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Why Has the Cost of Fixed-Wing Aircraft Risen?

A Macroscopic Examination of the Trends in U.S. Military Aircraft Costs over the Past Several Decades

Mark V. Arena • Obaid Younossi • Kevin Brancato
Irv Blickstein • Clifford A. Grammich

Prepared for the
United States Navy and United States Air Force

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RAND NATIONAL DEFENSE RESEARCH INSTITUTE and
PROJECT AIR FORCE

The research was conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute (NDRI) and the Resource Management Program of RAND Project AIR FORCE (PAF). Both NDRI and PAF are federally funded research and development centers sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community under contracts W74V8H-06-C-0002 and PFA7014-06-0001.

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Preface

In recent decades, cost escalation for military fixed-wing aircraft of all types has exceeded that of commonly used inflation indices, including the Consumer Price Index, the Department of Defense procurement deflator, and the Gross Domestic Product deflator.[1] A relatively fixed investment budget (albeit one with cyclical variations) means that the Services must somehow accommodate higher unit costs. This accommodation may mean buying fewer aircraft than in the past or it may mean reprioritizing budgets between acquisition and operations and support.

This monograph explores the causes of this unit cost escalation, including both economy-driven factors that the Services cannot control and customer-driven factors that they can.

The research was conducted between January 2006 and September 2007 and was jointly sponsored by the Assessment Division, Office of the Chief of Naval Operations (OPNAV N81) and by the Principal Deputy, Office of the Assistant Secretary of the Air Force (Acquisition), Lt Gen Donald Hoffman, SAF/AQ, and Blaise Durante, SAF/AQX.

The research was conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute (NDRI) and the Resource Management Program of RAND Project AIR FORCE (PAF). Both NDRI and PAF are federally funded research and development centers sponsored by the Office of the Sec-

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[1] This study exclusively examines manned aircraft and data. Unmanned aerial vehicles (UAVs) are excluded from the analysis.

retary of Defense, the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

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RAND Project AIR FORCE reports that address military aircraft cost estimating issues include the following:

- In *An Overview of Acquisition Reform Cost Savings Estimates,* MR-1329-AF, Mark A. Lorell and John C. Graser use relevant literature and interviews to determine whether estimates of the efficacy of acquisition reform measures are robust enough to be of predictive value.
- In *Military Airframe Acquisition Costs: The Effects of Lean Manufacturing,* MR-1325-AF, Cynthia R. Cook and John C. Graser examine the package of new tools and techniques known as "lean production" to determine whether it would enable aircraft manufacturers to produce new weapon systems at costs below those predicted by historical cost-estimating models.
- In *Military Airframe Costs: The Effects of Advanced Materials and Manufacturing Processes,* MR-1370-AF, Obaid Younossi, Michael Kennedy, and John C. Graser examine cost-estimating methodologies and focus on military airframe materials and manufactur-

ing processes. The authors provide cost estimators with factors useful in adjusting and creating estimates based on parametric cost-estimating methods.

- In *Military Jet Engine Acquisition: Technology Basics and Cost-Estimating Methodology*, MR-1596-AF, Obaid Younossi, Mark V. Arena, Richard M. Moore, Mark A. Lorell, Joanna Mason, and John C. Graser present a new methodology for estimating military jet engine costs and discuss the technical parameters that derive the engine development schedule, development cost, and production costs and present a quantitative analysis of historical data on engine development schedule and cost.
- In *Test and Evaluation Trends and Costs for Aircraft and Guided Weapons,* MG-109-AF, Bernard Fox, Michael Boito, John C. Graser, and Obaid Younossi examine the effects of changes in the test and evaluation (T&E) process used to evaluate military aircraft and air-launched guided weapons during their development programs. The report also provides relationships for developing estimates of T&E costs for future programs.
- In *Software Cost Estimation and Sizing Methods, Issues and Guidelines,* MG-269-AF, Shari Lawrence Pfleeger, Felicia Wu, and Rosalind Lewis recommend an approach to improve the utility of the software cost estimates by exposing uncertainty and reducing risks associated with developing estimates.
- In *Lessons Learned from the F/A-22 and F/A-18E/F Development Programs,* MG-276-AF, Obaid Younossi, David E. Stem, Mark A. Lorell, and Frances M. Lussier evaluate historical cost, schedule, and technical information from the development of the F/A-22 and F/A-18E/F programs to derive lessons for the Air Force and other Services to improve the acquisition of future systems.
- In *Price-Based Acquisition: Issues and Challenges for Defense Department Procurement of Weapon Systems,* MG-337-AF, Mark A. Lorell, John C. Graser, and Cynthia R. Cook document savings and cost avoidance on government and contractor activities resulting from the use of price-based acquisition strategies in a manner useful to the acquisition, planning, and cost-estimating communities, and generate recommendations for approaches to more accurately

assessing the potential cost savings and cost avoidance that can be expected from the wider use of price-based acquisition.

- In *Impossible Certainty: Cost Risk Analysis for Air Force Systems,* MG-415-AF, Mark V. Arena, Obaid Younossi, Lionel A. Galway, Bernard Fox, John C. Graser, Jerry M. Sollinger, Felicia Wu, and Carolyn Wong describe various ways to estimate cost risk and recommend attributes of a cost-risk estimation policy for the Air Force.
- In *Systems Engineering and Program Management: Trends and Costs for Aircraft and Guided Weapons Programs,* MG-413-AF, David E. Stem, Michael Boito, and Obaid Younossi evaluate the historical trends and develop a cost-estimating method for systems engineering and program management, which is one of the most costly "below-the-line" items for military aircraft and guided weapon systems.
- In *Evolutionary Acquisition: Implementation Challenges for Defense Space Programs,* MG-431-AF, Mark A. Lorell, Julia F. Lowell, and Obaid Younossi study how to help the Air Force acquisition community formulate policies that anticipate and respond to the prospect of more widespread use of evolutionary acquisition strategies relying on a spiral development process, as recently mandated by the Office of the Secretary of Defense.
- In *Historical Cost Growth of Completed Weapon System Programs,* TR-343-AF, Mark V. Arena, Robert S. Leonard, Sheila E. Murray, and Obaid Younossi conduct a literature review of cost growth studies and provide a more extensive analysis of the historical cost growth of the completed acquisition programs.
- In *Is Weapon System Cost Growth Increasing? A Quantitative Assessment of Completed and Ongoing Programs*, MG-588-AF, Obaid Younossi, Mark V. Arena, Robert S. Leonard, Charles Robert Roll, Jr., Arvind Jain, and Jerry M. Sollinger analyze completed and ongoing weapon system programs' development cost growth and determine the magnitude of cost growth and show cost growth trends for the past three decades.

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Summary

As with many other military weapon systems, military aircraft have experienced long-term, unit cost increases that are greater than the rate of inflation.[1] These increases, largely driven by the desire for greater capabilities, appear likely to persist and could have dire implications for aircraft inventories, particularly given relatively fixed defense investment budgets. Commenting on the continually increasing costs for aircraft, one industry executive (Augustine, 1986, p. 143) famously wrote,

> In the year 2054, the entire defense budget will purchase just one aircraft. The aircraft will have to be shared by the Air Force and Navy 3½ days per week except for leap year, when it will be made available to the Marines for the extra day.

Given increasing costs for military aircraft, relatively fixed budgets to procure them, and resulting decreased procurement rates, the Air Force and the Navy asked RAND to examine the causes of military aircraft cost escalation. From available data, we calculated cost escalation rates as well as their "economy-driven" and "customer-driven" causes.

For every type of aircraft we examined—patrol, cargo, trainer, bomber, attack, fighter, and electronic warfare—annual unit cost esca-

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1 Throughout this document, we use the terms *price* and *cost* interchangeably. Formally, in most cases we are referring not to cost but to what cost estimators term as *price*, that is, the actual dollars required to buy the system (including all fees and profits). By *cost increase* (or *cost escalation*), we mean the differences in actual prices paid for aircraft over time and not the difference between the estimated and actual values.

lation rates in the past quarter century have exceeded common inflation indices, such as the Consumer Price Index, the Department of Defense procurement deflator, and the Gross Domestic Product deflator. This trend is true whether cost escalation is measured using either procurement or flyaway cost. Patterns of cost escalation differed by aircraft—some showed cost improvement over time, while others steadily increased—but, again, all exceeded that for other inflation measures.

We considered two groups of contributors to cost escalation: economy-driven variables, which include costs for labor, equipment, and material, and customer-driven variables, which include costs for providing performance characteristics that the Services want in their aircraft.

We found that the rates ($/hr) of aircraft manufacturing labor, in both direct and fully burdened wages, have increased much faster than other measures of inflation. Nevertheless, increased productivity has meant that overall, labor costs have grown only slightly faster than inflation. Furthermore, the proportion of labor cost in the overall cost of aircraft has been steadily decreasing (from a prime contractor perspective) as more manufacturing is outsourced. With two exceptions (specialty metals and avionics systems, such as navigation equipment), materials and equipment used in aircraft manufacturing have increased in cost at roughly the same rate as other measures of inflation. Altogether, we find that labor, material, equipment, and manufacturer fees and profits have helped increase the cost of aircraft about 3.5 percent annually—which is less than the rate of increase for some inflation indices during the same time.

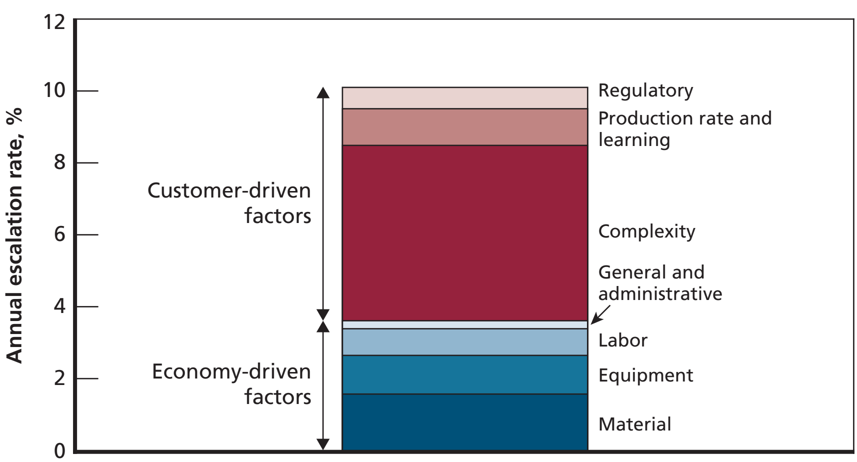
The government can affect the cost of military aircraft in several ways, particularly through the quantity it demands and the characteristics it specifies. Although we did not find a consistent cost improvement effect stemming from purchases over time in aircraft procurement, we did find a procurement rate effect by which higher production rates helped reduce unit prices. One reason for this may be the economic leverage from larger purchases that allows manufacturers to invest in efficiency improvements. Other possible reasons are the spreading of fixed overhead costs over more units—thus reducing average unit price.

Another explanation could be more efficient use of labor and tooling when production rates are higher.

When considering comparison pairs of aircraft, we found that complexity of the aircraft (performance characteristics and airframe material) contributed to aircraft cost escalation, often at rates far exceeding those of inflation. Figure S.1 shows the contributions of the various factors to cost escalation when comparing an F-15A (1975) to an F-22A (2005). The chart shows that roughly a third of the overall cost escalation is due to economy-driven factors. The remainder is due to customer-driven ones—mainly system complexity.

Interviews that we conducted with representatives of aircraft manufacturers confirmed many of these findings. In particular, these representatives noted that the increased demand for greater aircraft stealth and reduced aircraft weight contributed to cost escalation. They also cited government regulations, such as those designed to protect American industry and technology and those for environmental protection and occupational health as sources of aircraft cost escalation.

Figure S.1
Contributors to Price Escalation from the F-15A (1975) to the F-22A (2005)



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The Services could choose to address cost escalation in several ways, some more feasible than others. Improved procurement stability and longer-term contracts could encourage manufacturers to make investments to increase efficiency and cut costs. Fewer change orders to aircraft may help reduce costs as well. International competition and participation in the construction of military aircraft could also reduce costs, although this would likely be opposed by Congress and might be feasible only for noncombat aircraft. Focusing on aircraft upgrades in successive model improvements rather than on acquisition of new aircraft types, as has been done for several aircraft (e.g., the F/A-18E/F), could help contain procurement cost escalation, although the age of some existing aircraft may limit the application of this practice.

At present, the Air Force and the Navy appear to be opting for fewer aircraft but with the highest technological capabilities. Such a strategy helps ensure that U.S. aircraft remain far superior to those of any other military in the world. Maintaining such capabilities, however, does have a cost. We do not evaluate whether this particular tradeoff is good or bad. We note only that it exists and point out related issues that the Services will have to address in deciding how to allocate future appropriations for aircraft procurement.

Acknowledgments

Many individuals contributed to this study and we would like to thank them. First, we thank Trip Barber of OPNAV N81 for both cosponsoring this study and providing very useful input and guidance along the way. We would also like to thank Blaise Durante (SAF/AQX) for also cosponsoring this project and for his long-term support of Project AIR FORCE's cost research.

We are grateful to the U.S. manufacturers and their parent organizations—Boeing, Lockheed Martin Corporation, and Northrop Grumman Corporation—for their time and insight. Particularly, we thank Laura Russell and Ken Goeddel (Boeing); Richard Janda, Larry McQuien, and Doug Steen (Lockheed Martin); and Chris Bowie (Northrop Grumman) for coordinating our interactions with industry and providing helpful data for the study. We are also grateful to David Burgess, Donald Allen, and Soroja Raman of NAVAIR for helpful technical discussions and data on Navy fixed-wing programs. Richard Hartley (SAF/FMC) and Jay Jordan from the Air Force Cost Analysis Agency provided similar help and guidance for Air Force systems.

Finally, we acknowledge both reviewers of this document: John Graser (RAND) and Bill Stranges (former NCAD and NAVAIR official). Their comments and suggestions greatly improved this work.

Abbreviations

ACEA	Arms Control Export Act
APN	Aircraft Procurement Navy
B&P	bid and proposal
BLS	Bureau of Labor Statistics
CAD	computer-aided design
CAIV	Cost as an Independent Variable
CAM	computer-aided manufacturing
CBO	Congressional Budget Office
CC	configuration change
CCDR	Contractor Cost Data Report
CDRL	Contract Data Requirements List
CFE	contractor-furnished equipment
CI	cost improvement
CIC	cost improvement curve
CPI	Consumer Price Index
CTOL	conventional take off and landing
CV	carrier version
DCARC	Defense Cost and Resource Center
DoD	Department of Defense
ECI	Employment Cost Index
EVM	earned value management
EW	empty weight

FY	fiscal year
G&A	general and administrative
GDP	Gross Domestic Product
GFE	government-furnished equipment
HAPCA	Historical Aircraft Procurement Cost Archive
IPT	integrated product team
IR&D	internal research and development
ITAR	International Trade in Arms Regulations
JSF	Joint Strike Fighter
LM	Lockheed Martin
MMA	multi-mission maritime aircraft
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVAIR	Naval Air Systems Command
NGC	Northrop Grumman Corporation
OPNAV	Office of the Chief of Naval Operations
OSD	Office of the Secretary of Defense
OSHA	Occupational Safety and Health Administration
PA&E	Program Analysis and Evaluation (OSD)
PPI	Producer Price Index
PR	procurement rate
QC	quality control
R&D	research and development
RAM	radar absorbing materials
SAR	Selected Acquisition Report
SEC	Securities and Exchange Commission
STOVL	short take off and vertical landing
UAV	unmanned aerial vehicle
USAF	U.S. Air Force
USN	U.S. Navy

CHAPTER ONE

The Escalation of Aircraft Costs

Commenting on the continually increasing costs of military aircraft, Norman Augustine (1986, p. 143) famously observed,

> In the year 2054, the entire defense budget will purchase just one aircraft. This aircraft will have to be shared by the Air Force and Navy 3½ days per week except for leap year, when it will be made available to the Marines for the extra day.

Augustine based this prediction on costs for individual aircraft that had grown by a factor of four every decade, with increases more closely related to the passage of time than to modifications in speed, weight, or technical specifications.

The trends that Augustine observed have persisted across time and weapon systems. Unit costs for weapons have typically grown at least 5 percent annually, with those for advanced weapon systems such as tactical aircraft growing 10 percent annually (Hellerman, 2003; Kirkpatrick, 2004). Among recent aircraft series, for example, the unit costs for the F-15 increased from $11.9 million in 1974 (as measured in then-year dollars) to $54.0 million in 2000.[1] Eskew (2000) observed that the real cost escalation (beyond inflation and performance growth) for military aircraft is about 3 percent per year.

Although design improvements may explain some increases, it is remarkable that other advances have not helped minimize them. As

[1] Expressing this difference in constant 2006 dollars, the trend is $44.0 million in 1974 versus $58.6 million in 2000.

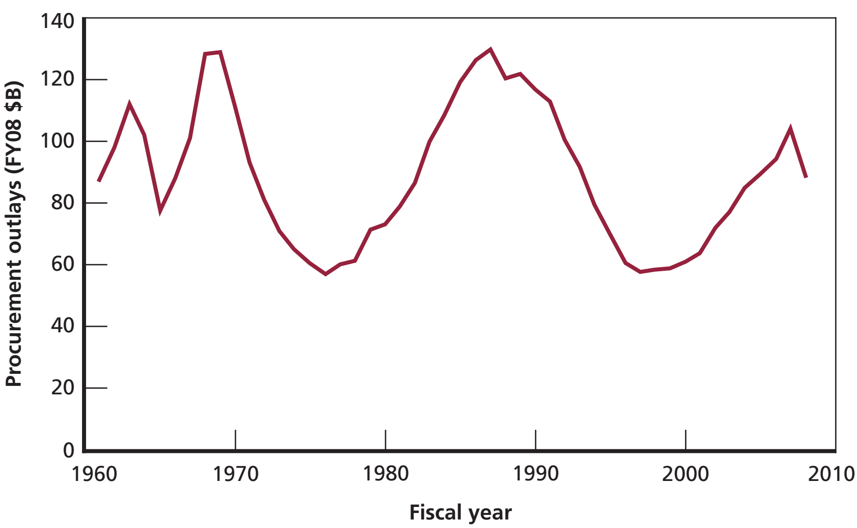
Dov Zakheim (2005), the former Under Secretary of Defense (Comptroller), noted, such

> findings are not easy to fathom. One might have thought that more efficient production methods, including computer aided design and manufacturing, microminiaturization of components, and the employment of greater computing power, all would have reduced costs or at least held them level.

These trends, as Augustine would note, have dire implications for the number of aircraft the U.S. Air Force (USAF) and the U.S. Navy (USN) can procure. One way to demonstrate this is through the numbers of aircraft that the Department of Defense (DoD) has been able to procure through recent budget cycles.

In recent decades, defense procurement spending has been cyclical, fluctuating since the mid-1960s between \$60 billion and \$130 billion in constant dollars (Figure 1.1) (Office of Under Secretary of Defense, 2007b). After peaking during the late 1960s, outlays decreased

Figure 1.1
Cyclical Defense Procurement Outlays, Between Fiscal Years 1960 and 2008



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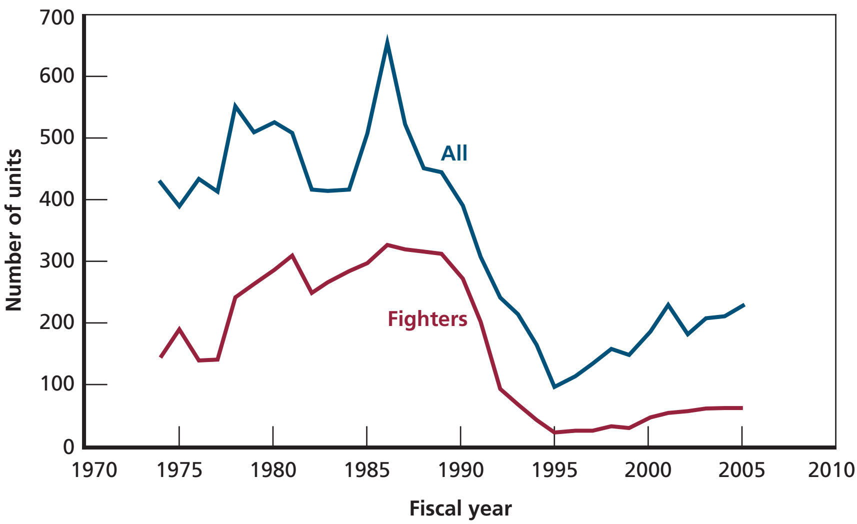
through the early 1970s, increased through the mid-1980s, and decreased following the end of the Cold War and the first Gulf War through the late 1990s. They have increased since then, because of the Global War on Terror operations, but are expected to decrease again in the near future.

During this same time, the number of aircraft that DoD has purchased has cycled with the procurement budget (Figure 1.2), but with an overall downward trend. For example, when total outlays "troughed" in 1975, DoD procured 193 fighter aircraft and 391 total aircraft. When outlays peaked in 1985, DoD procured 300 fighter aircraft and 509 total aircraft. When they troughed again in 1995, DoD procured only 24 fighter aircraft and 101 total aircraft. In 2005, when outlays peaked again, it procured 66 fighter aircraft and 231 total aircraft, or roughly half what it procured annually in the trough of the mid-1970s and roughly a third what it procured annually during the last peak of the mid-1980s.

Figure 1.2
Annual Quantity of Aircraft Procured, 1974 to 2005



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To be sure, other variables, such as changing threats and missions, can affect the procurement of aircraft and their composition in any given period of time. Yet the escalating cost of aircraft and the downward cycle of procurement rates raise issues about the number of aircraft DoD will ultimately be able to procure and operate.

The Navy has faced similar issues in procuring ships. Since the mid-1960s, the cost of ships has increased from 100 to 400 percent (Clark, 2005; Arena et al., 2006a).

Concerns over these trends led the Navy and Air Force to ask RAND to address sources of cost escalation in procuring military fixed-wing aircraft. The issues we address are:

- How does escalation in aircraft costs compare with cost escalation in other sectors of the economy?
- What are the sources of any escalation in these costs?
- Can cost escalation be reduced or minimized?

In the next chapter, we examine some measures of cost escalation and their trends. In Chapter Three, we examine "economy-driven" sources of cost escalation, or those associated with labor, material, and equipment, over which the Services have little control. In Chapter Four, we examine "customer-driven" sources of cost escalation, including how quantities ordered, changing configurations, and desired technical characteristics all affect aircraft costs. Chapter Five offers some pairwise comparisons of how both economy-driven and customer-driven characteristics have contributed to aircraft cost escalation. We present views of some industry representatives on the sources of cost escalation in Chapter Six. Next, we discuss some options for addressing cost escalation in Chapter Seven. Finally, we present our conclusions in Chapter Eight.

CHAPTER TWO

Data and Price Trends

Data Sources and Normalization

Military fixed-wing aircraft systems differ widely by size, speed, range, weight, airframe material composition, length of production run, production rate, and costs. Differences *within* aircraft mission (or class)—attack, bomber, cargo, electronic, fighter, patrol, and trainer—can be considerable as well.[1] A single aircraft design can have blocks or series that differ considerably. Even within the same block or series, costs can increase from tail to tail as newer technology is gradually introduced on the production line. In this monograph, we distinguish between aircraft type (e.g., F/A-18) and aircraft series (e.g., F/A-18C/D versus F/A-18E/F) but not block configurations (because of data limitations). When assessing cost at the annual buy level, we use a single set of technical characteristics for all aircraft bought in that fiscal year.

To begin addressing aircraft cost issues, we review three topics in this chapter. First, we examine available data sources, including their limitations. Second, we discuss how to measure cost escalation. Third, we assess how cost escalation for aircraft compares with other measures of cost inflation such as the Consumer Price Index (CPI), the DoD procurement deflator, and the Gross Domestic Product (GDP) deflator.

1 DoD has a standard nomenclature for its aircraft using the "mission/design/series" convention. For example, the F/A-18E/F means it is a fighter/attack mission aircraft, the 18th in the series of aircraft of that mission designated by DoD, and it is the 5th and 6th series within that mission and design.

Sources of Data and Their Content

With one exception,[2] we analyze total budgeted system cost for aircraft throughout this document. These costs are labeled Gross P-1 in budget documents.[3] In addition to airframe, propulsion, and avionics costs (usually referred to as "recurring flyaway"), Gross P-1 includes "below-the-line" elements: support equipment, training equipment, publications, and technical data.

We developed an annual cost and quantity database using three primary sources of information: the Historical Aircraft Procurement Cost Archive (HAPCA), a Congressional Budget Office (CBO) (1992) study which documented cost and quantity data for all the military services between 1974 and 1994, and P-1 budget documents. HAPCA, developed by the Naval Air Systems Command (NAVAIR), contains procurement data (cost and quantity) for aircraft systems procured by the Navy from the late 1940s to 2000, including subsystem and below-the-line elements. HAPCA does not contain Navy procurement cost data for any aircraft past 2000.[4] For the Air Force and more recent Navy programs, we therefore compiled comparable total-system-level cost data using a combination of the CBO and P-1 budget data. The resulting overall cost database covered the years 1974 through 2006 for all Air Force and Navy fixed-wing procurements that were not classified. All three data sources were fairly consistent at the top-line level,

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[2] In Table 2.2, we explore the difference in price escalation for procurement versus flyaway costs.

[3] Given the complexity of aircraft and the technologies involved, certain parts may have to be ordered earlier than other parts of the aircraft to have everything ready to meet the final assembly schedule. Recognizing this, Congress often authorizes and appropriates funds for these "long-lead items" in a fiscal year before the funds needed for the rest of the aircraft in that annual buy. These funds are entitled "advance procurement" funds and are shown on the budget documents as such. Although Net P-1 accrues "advance procurement" funds to the budget year that the funds were allocated, Gross P-1 accrues "advance procurement" to the annual buys that the funds are used to purchase.

[4] HAPCA data included only estimates for fiscal year 2000. We replaced these with actual cost data in our database.

which was not surprising given that the HAPCA and CBO dataset were built from the original P-1 documents.[5]

Technical and Schedule Databases

To understand the causes of cost escalation, we needed a database with detailed technical characteristics for each aircraft model. HAPCA contains data on performance and weight—including cruising and maximum speed, empty and maximum weight, avionics weight, combat radius, engine thrust, and materials composition[6]—for both Navy and Air Force aircraft. However, much of the technical information HAPCA contains is incomplete and does not document the sources of information or the underlying assumptions such as operating conditions or maximum speed evaluated.

We expanded these data with figures in published documents, proprietary-source documents, and publicly available databases. Published documents include a NASA history on modern aircraft (Loftin, 1985), *Jane's All the World's Aircraft* (Jane's Information Group, annual), RAND publications (Large, Campbell, and Cates, 1976; Dryden, Britt, and Binnings-DePriester, 1981; Resetar, Rogers, and Hess, 1991), and other government-sponsored research (Groemping and Noah, 1977; Heatherman, 1983). Other documents referenced for technical specifications include NAVAIR's Standard Aircraft Characteristics, and Beltramo et al. (1977). Proprietary-source documents included information acquired from contractor internal documents and presentations. Publicly available databases include Air Force and Navy current and historical factsheets and those of enthusiast associations.[7]

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5 The P-1 database quantity information for USN matched but the overall cost numbers were sometimes off by as much as ±1 percent because of rounding.

6 The materials composition database contains the percentage of airframe structure that is aluminum, steel, titanium, composite, or other.

7 Air Force factsheets include those available at http://www.af.mil/factsheets/ and http://www.nationalmuseum.af.mil/factsheets/. Navy factsheets include those available at http://www.navy.mil/navydata/fact.asp and http://www.history.navy.mil/branches/org4-20.htm. Enthusiast data are available at http://www.aero-web.org, http://www.aerospaceweb.org/, and http://www.spacey.net/airplane/. All these Web sites were accessed February 9, 2007.

Data Limitations

We note some limitations to our cost and technical data and analyses. First, we have limited the analysis to the total cost level. Although the HAPCA database has a subelement breakout of cost, "government-furnished equipment (GFE)" is added to "airframe." This prevented us from analyzing cost escalation at a subsystem level (e.g., avionics and airframe) as we originally intended because in many cases large portions of the subsystem costs are GFE. Second, although we are concerned only with production costs, the early fiscal year buys are likely to overlap with some research and development dollars as well, leading to a potential understatement of procurement costs for the first few lots. Third, because our technical characteristics database is compiled from several secondary sources, it is only approximate, representing "average" or consensus figures, and not necessarily the results of physical validation or testing. Fourth, procurement quantities include only those purchased by USN and USAF. Large foreign procurement of similar variants of some aircraft systems could have cost consequences, such as those we examine below in which larger total quantities (including foreign sales) can help reduce unit costs.

Adjustments and Normalization

Where appropriate,[8] we adjusted costs for inflation by using the standard Navy aircraft procurement (APN) deflator (Office of Budget, 2004) to a fiscal year 2006 basis. We also considered several other deflators in the first stage of our analysis, but none had substantial effects on regression coefficients or other numerical results.[9]

Final Dataset and Systems Represented

Our work is multistage, with each stage considering a different number of systems. We considered all aircraft for which we had data in our analysis of cost escalation trends. In estimating cost improvement and

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8 This normalization process was used for our analysis of customer-driven factors described in Chapter Four. Elsewhere in the document, we use nonnormalized values.

9 That is, none of the other deflators resulted in changes of more than ±1 in the second significant digit in our cost improvement or production rate coefficient estimates.

production rate effects on aircraft costs, we assessed only those systems that met certain statistical criteria (described below). In estimating the effects of technical characteristics on aircraft costs, we included all systems for which we had a complete set of cost and technical data, regardless of the number of annual buys. We could not find airframe materials data for all the aircraft used for the technical characteristics analysis, so our material complexity analysis is based on a further reduced set of aircraft. Appendix A lists all systems assessed in each part of our analysis.

Measuring Cost Escalation

We focus on long-term changes in price,[10] or what we call *cost escalation*. We use this term to describe the general changes in price, typically for a similar item or quantity, between periods of time. It is important to distinguish escalation from growth. *Cost growth* is the difference between actual and estimated costs. It reflects how well we can predict the cost of a future system. We are not concerned with the quality of aircraft price predictions; rather, we are studying how the actual price for an aircraft changed as time passed.[11]

We quantify the escalation in terms of annual growth rates. We chose this approach to minimize distortions caused by examining trends over differing periods of time. If we were to examine the simple increase in price (i.e., final to initial cost), our results would depend on the amount of time between the two values being compared. In general, longer periods of time would lead to greater price increases. By calculating *annual growth rates,* we normalize cost increases to a common baseline.

Algebraically, we define *annual cost growth* as

10 Throughout this document, we use the terms *price* and *cost* interchangeably. Formally, in most cases we are referring not to cost but to what cost estimators term as price, that is, the actual dollars required to buy the system (including all fees and profits).

11 For examples of cost growth on defense weapon systems, see Arena et al. (2006b).

$$\text{rate} = \sqrt[(\text{Year}_2 - \text{Year}_1)]{\frac{\text{Cost}_2}{\text{Cost}_1}} - 1 \;, \tag{2.1}$$

where

- Cost_2 is the cost at Year_2, and
- Cost_1 is the cost at Year_1.

That is, the *annual growth rate* is a compound function in which year-to-year increases accumulate. If, for example, Cost_2 is \$5 and Year_2 is 2004, and Cost_1 is \$4 and Year_1 is 1998, then the resulting *annual growth rate* for cost may be calculated as 3.8 percent.[12] For cases where we have more than two observations, we use optimized least squares regression to calculate an annualized growth rate. The regression approach fits the natural logarithm of cost (the dependent variable) as a function of the fiscal year (the independent variable). The annual rate is the exponential of the coefficient for the fiscal year, minus one.

Trends

The first issue we address is how the long-term cost growth for fixed-wing aircraft compares with other measures of inflation. Table 2.1 shows the annual escalation rate in the unit procurement cost[13] for various types of fixed-wing aircraft as well as common measures of inflation including the CPI, the DoD procurement deflator, and

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[12] Mathematically, the terms in this example are, $\text{Year}_2 - \text{Year}_1 = 2004 - 1998 = 6$ and $\text{Cost}_2/\text{Cost}_1 = 5/4 = 1.25$. The sixth root of 1.25 is approximately 1.0379; subtracting one from this gives an annual growth rate of 0.0379, or approximately 3.8 percent.

[13] We examine unit procurement cost trends as we have the most complete set of cost data with respect to timeframe. However, below we address the trends in terms of recurring flyaway costs as well. As the name implies, flyaway costs are costs that directly lead to specific aircraft units (e.g., hardware, change orders, GFE, and management). Procurement costs encompass all flyaway costs and those indirect costs not associated with a specific aircraft unit, such as spare parts, data, contractor support, and training equipment, but are necessary to operate and maintain the fleet.

Table 2.1
Average Annual Cost Escalation for Aircraft and Inflation Indices, 1974 to 2005

Aircraft Type	Average Annual Rate, %
Patrol	11.6
Cargo	10.8
Trainer	9.1
Bomber	8.4
Attack	8.3
Fighter	7.6
Electronic	6.7

Inflation Index	Average Inflation Rate, %
CPI	4.3
DoD procurement deflator	3.8
GDP deflator	3.7

the GDP deflator. These growth rates represent the rates of increase between 1974 and 2005, unadjusted for inflation. We determined these escalation rates using the regression approach described above. Appendix A lists all aircraft included in each aircraft type.

By type, cost escalation for aircraft in the past quarter-century has varied from about 7 to 12 percent. This rate of escalation is similar to that seen in Navy ships since 1965 (Arena et al., 2006a). The long-term escalation rate has also been greater than that for common measures of inflation. Even the rate of increase for electronic warfare aircraft, with the lowest rate of increase of the types listed above, was above that of other inflation indices.

The ordering of aircraft from highest to lowest rate of increase is noteworthy. Surprisingly, patrol aircraft top the list, with an annual cost growth rate more than double that for any inflation measure. One might have anticipated that more technically advanced systems, such as fighters and attack aircraft, would have the highest rates. The rate for patrol aircraft is a result of the limited duration of the P-3 program—which dominates the trend for this type. This program ran from fiscal

year 1974 to fiscal year 1987, a period in which inflation indices ranged from 6.2 to 7.3 percent. This partially accounts for the higher rate of escalation seen in costs for patrol aircraft than seen for other aircraft produced in times of lower inflation. Cargo aircraft had the second highest rate of increase, also more than double that for any of the common measures of inflation we note. This, too, is somewhat surprising, given that such aircraft tend to have less complexity, including fewer mission systems and fewer requirements for avionics and weapons. One reason for the high rate of increase for cargo aircraft may be the significant increases made to their capability (e.g., payload rate, range, speed). We will explore such changes in subsequent chapters.

One question that arose during our early evaluation of the data was whether unit procurement costs might misrepresent overall trends in cost escalation. To assess this possibility, we compare, in Table 2.2, the unit procurement and flyaway cost[14] trends from 1974 to 2000 using HAPCA data (which contain Navy aircraft only, as discussed above). Although the rates of procurement cost escalation in the HAPCA data differed from those in the P-1 data,[15] we found little difference between the rates of increase for procurement or flyaway costs in the HAPCA data. This similarity in escalation rates for the two different costs suggests that our results are not biased by using P-1 rather than unit flyaway cost.

The rates of escalation were not uniform (or monotonically increasing) over the 30-year period. Figure 2.1 plots the average unit procurement cost by fiscal year for various fighter aircraft models.

Some aircraft, such as F-18E/F and F-22A, show a traditional cost improvement trend. In the initial years of procurement of these systems, there is a higher average unit cost that decreases exponentially

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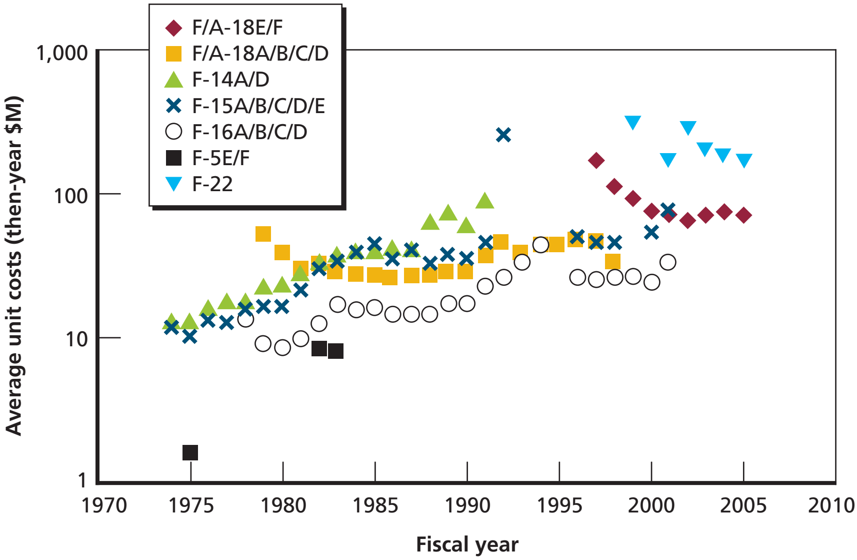
[14] Flyaway costs are generally considered to be more representative of the true "hardware" cost because they exclude such items as support, initial spares, and other contractor support services that might differ greatly by system.

[15] We found that trainer aircraft, for example, have a procurement cost growth rate of 13.8 percent annually in the HAPCA data, as shown in Table 2.2, but of only 9.1 percent in the P-1 data, as shown in Table 2.1. The difference results because the P-1 data include a broader set of systems, such as the T-34 and the Joint Primary Aircraft Training System, most with lower rates of cost increase, that are not in the HAPCA data.

Table 2.2
Average Annual Escalation Rate for Unit Procurement and Flyaway Costs for Various Navy Aircraft, 1974 to 2000

Aircraft Type	Procurement, %	Flyaway, %
Trainer	13.8	14.1
Cargo	13.2	13.0
Patrol	11.2	9.9
Attack	8.2	8.4
Electronic	7.7	7.5
Fighter	6.5	6.2

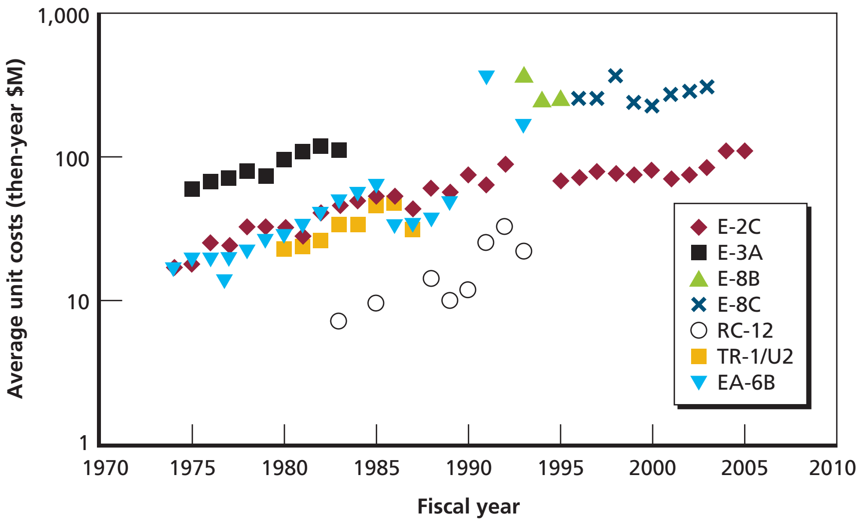
Figure 2.1
Average Unit Procurement Costs for Fighter Aircraft, by Fiscal Year, 1974 to 2005



RAND *MG696-2.1*

in subsequent years, and eventually levels off. Other aircraft, such as F-14A/D, display a steady increase in average unit cost in subsequent fiscal years, as do electronic aircraft, as shown in Figure 2.2. Still other

Figure 2.2
Average Unit Procurement Costs for Electronic Aircraft, by Fiscal Year, 1974 to 2005



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aircraft, such as F-16 and F-15, show a mixed pattern with plateaus whose duration are likely related to model changes.

In contrast to the different patterns of cost growth for aircraft, those observed for naval ships in earlier research (Arena et al., 2006a) generally followed the traditional cost improvement pattern. This suggests that fixed-wing aircraft, in general, are more subject to modification and upgrade over the life of a program. In fact, it is not uncommon for an aircraft to have several planned upgrades over its production life. These upgrades are typically driven by changes in requirements, obsolescence issues, or the need to mitigate risk by deliberately incorporating new technologies later in production. For example, the F-16 grew in capability over its production run. Its aircraft empty weight grew from 15,600 to 19,200 pounds between Block 10 (F-16A/B) and Block 50 (F-16C/D), its engine was upgraded from an F-100-PW-200 to either an F-110-GE-129 or an F-100-PW-229, and it had numerous other upgrades in its avionics and mission systems.

Ideally, we would next explore the sources of escalation within a single aircraft program at a more detailed level, such as the airframe, propulsion, or avionics. For example, in earlier analyses of naval ship cost escalation, we observed that most of the escalation in the FFG-7 ship class occurred in electronics systems, primarily government-furnished equipment. Unfortunately, we were not able to get a consistent set of data to do such a comparison for aircraft. Although the HAPCA data do show costs for lower-level work breakdown structures, the groupings are not as helpful because airframe costs and all contractor-furnished equipment (CFE) are grouped into one category, from which the separate effects of airframe, CFE, and GFE costs cannot be discerned.

Summary

No one set of data can offer comprehensive insights on cost and technical characteristics for military aircraft. The most complete set of cost data are those in P-1 budget submissions, which we use throughout our analysis. For technical parameters, we use a variety of sources of publicly available and contractor-provided information. We found that fixed-wing aircraft cost escalation has been about 2 to 7 percent greater than that for common measures of inflation. The trends of increase seemed to differ by system. Cost escalation data appear to reflect upgrades and improvements that have occurred within programs, as well as differences between programs. We turn next to the potential sources of this escalation, including both economic factors and those related to system complexity and capability.

CHAPTER THREE

Economy-Driven Factors

Economy-driven factors in aircraft cost escalation are those that the Services have little direct control over. These include such items as labor rates, material costs, and equipment costs.[1] For example, aircraft manufacturing wage rates increase over time because of overall changes in wages and prices throughout the economy, as well as changes in prevailing wages manufacturers must pay to retain skilled workers. All these variables are beyond the ability of the Services to control. In this chapter, we explore how these economy-driven factors have changed in recent decades, using a combination of data from the Bureau of Labor Statistics (BLS) and Contractor Cost Data Reports (CCDRs) for actual military aircraft.

Distribution of Costs

We used a series of CCDRs[2] to determine the relative importance of labor, equipment, and material costs in aircraft procurement. CCDRs include data on F-14, F-15, F-16, F-18A/B, F-18E/F, A-10, AV-8B,

1 The Services do have choices on which materials to use in an aircraft as well as on the nature and types of equipment used in it. We consider such variables in the next chapter, when we discuss how customer-specified performance can affect costs. Here, we consider elements that the Services cannot control directly, such as equipment and material that manufacturers use to build aircraft, as well as costs for manufacturers' labor.

2 CCDRs are provided to the government by contractors and detail the actual costs for the weapon systems purchased. We obtained these data from the Defense Cost and Resource Center (DCARC) Web site maintained by the Office of the Secretary of Defense Program

C-17, T-45, F-22A, C-2A, E-2C, F-5E, and S-3A aircraft. The selection was limited to those data readily available on the OSD PA&E Web site, which archives historical CCDRs. For each program, we selected early, middle, and late production points for analysis of trends. We limited our selection to three data points to avoid bias from a few programs with extensive CCDR histories. We use these data to analyze several cost issues in this chapter.

Table 3.1 shows the relative distribution of labor, equipment, and material costs in the CCDR data. These distributions do not include subcontract costs specifically identified in the CCDRs that are typically a mix of labor, material, and equipment, because we were unable to correct for allocations by prime contracting firms that historically included subcontracting costs as material costs in their CCDRs. The percentages are based on the weapon system cost breakouts in the CCDRs (air vehicle + system engineering and program management + integrated logistic support) that are comparable, but not identical, to the procurement costs shown earlier. (Procurement costs also include initial spares.)

Labor and equipment have accounted for most costs in these fixed-wing aircraft. These ratios, however, have not remained steady over time. Figure 3.1 shows the change in the percentages for these three components over time based on linear regression for the same CCDR data. The negative regression slope (downward trend) in labor

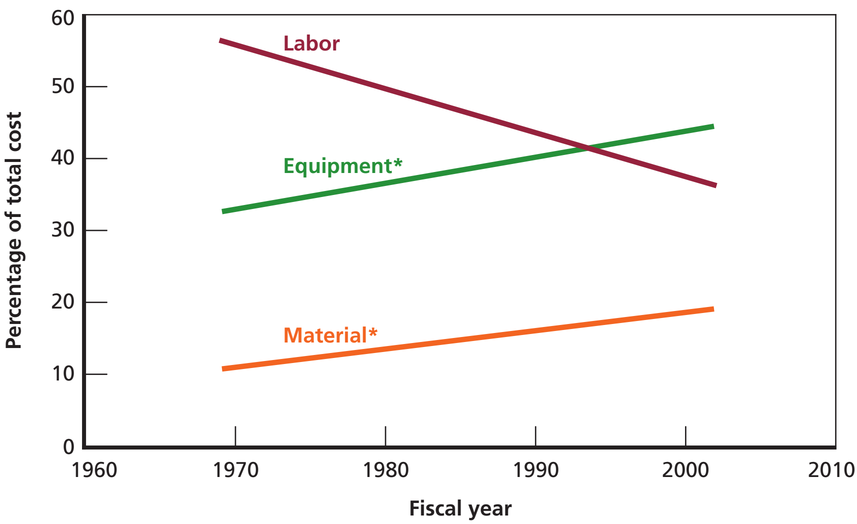
Table 3.1
Average Distribution of Labor, Equipment, and Material Costs for a Select Group of Fixed-Wing Aircraft, 1969 to 2003

Element	Percentage	Standard Deviation, %
Labor	47	16
Equipment	38	20
Material	15	13

Analysis and Evaluation (OSD PA&E). See http://dcarc.pae.osd.mil/default.aspx for more detail. We obtained a selection of the available reports between 1969 and 2003.

percentage is statistically significant (at the 5 percent level). This trend is likely due to two causes. First, productivity improvements and the use of lean manufacturing have helped reduce the amount of labor needed to perform similar functions.[3] Second, aircraft manufacturers have increasingly outsourced work when it is cost effective to do so, as, for example, in the machining of simple parts. Such an outsourcing would shift cost from labor to materials. Third, there has been a shift to advanced computer-aided design systems that have also been thought to improve the design process and reduce errors. However, the slopes for the material and equipment percentages are not significant to the 5 percent confidence level, and therefore we cannot definitively say where the shift out of labor has been.

Figure 3.1
Labor, Equipment, and Material Percentages of Weapon System Cost, 1969 to 2003



*Trend not statistically different.
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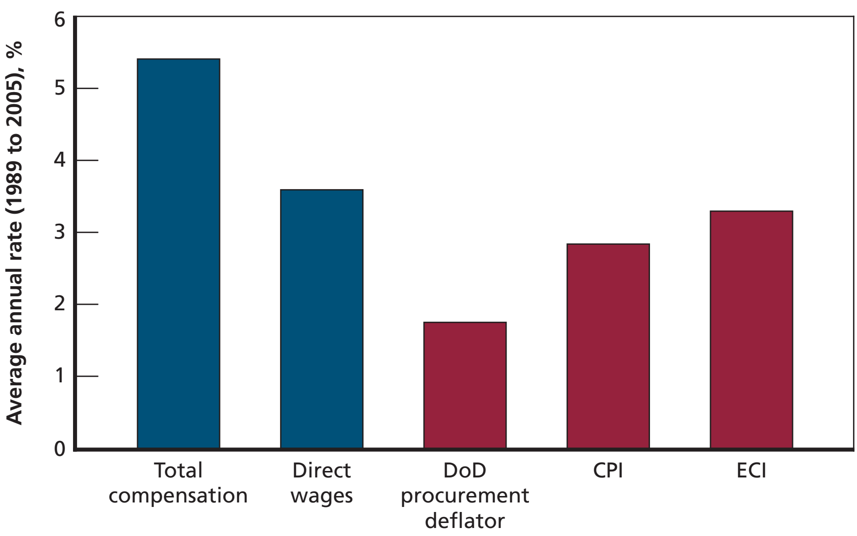
3 See Figure 3.5 for increases in aerospace labor productivity over time.

Below, we discuss in more detail individual economy-driven components of aircraft cost growth, including labor rates, material and equipment, and other related costs (i.e., general and administrative (G&A) and fee/profit). Because most CCDRs do not explicitly identify fees and profit, we rely on publicly available annual reports (10-Ks) to analyze profit trends.

Labor Rates

As described above, labor costs are a significant portion of the total system cost. Thus, changes in labor rates are of importance to understanding the influence of the economic factors. Figure 3.2 shows BLS data on the average annual increase for total compensation and direct wage rates in the aerospace sector (first two bars of Figure 3.2) compared with wage growth in the durable goods manufacturing industries

Figure 3.2
Average Annual Growth for Aerospace Labor Costs, 1989 to 2005



SOURCES: BLS and DoD.
RAND *MG696-3.2*

(Employment Cost Index (ECI) from 1989 to 2005).[4] It also shows two comparison indexes over this same timeframe—the CPI and the DoD procurement deflator.

A few important trends are evident in this figure. One is that the total compensation in the aerospace sector grew at a much higher rate than did direct wage rates. This suggests that the cost growth of health care and other benefits has outpaced general inflation. Earlier RAND research (Arena et al., 2006a) found a similar trend in the shipbuilding industry, in which health care and insurance costs contributed to faster growth for indirect wage costs. Unlike the shipbuilding industry, where unburdened labor rates grew at about the same rate as inflation measures, here we see that direct wages have grown slightly faster than the CPI, DoD deflator, or ECI, indicating that direct labor costs for the aerospace sector have also outpaced other common measures of inflation.

The CCDRs show an even greater annual rate of increase for the direct and burdened labor costs of military aircraft. Figure 3.3 shows the burdened and direct labor rates for the same set of aircraft programs used in Table 3.1.[5] These data indicate that direct labor rates have grown at an annual rate of 5.6 percent and the burdened rate has grown at a slightly higher rate of 5.9 percent (exponential fits). Note that there is considerably more variability around the fit trend line for the burdened data because other factors, such as business base,[6] are important for determining this rate.

These labor rates can be further broken down into four subcomponents: engineering, tooling, quality control (QC), and manufacturing. Table 3.2 shows the direct and indirect rate increase for these four subcomponents. Growth for all four elements, whether direct or

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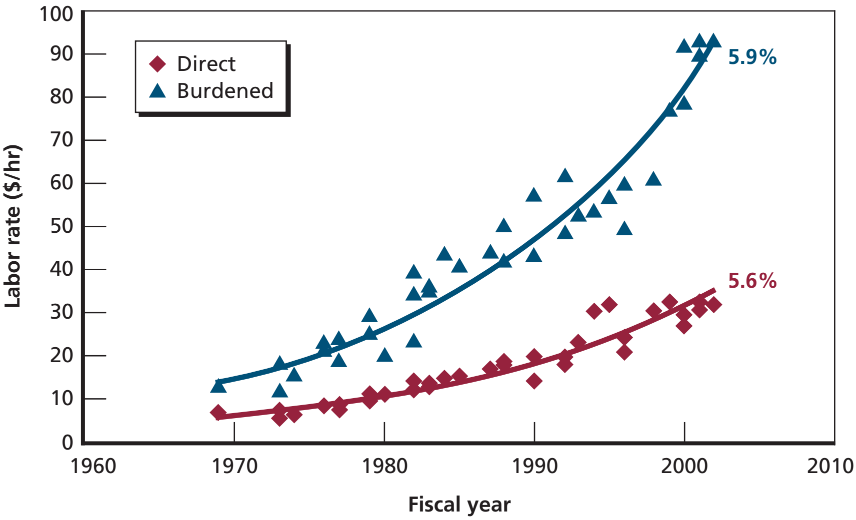
4 The range of dates was limited by data availability from the BLS.

5 Note that total compensation and burdened labor rates are not the same. Burdened labor includes total compensation in addition to other indirect costs such as corporate insurance, maintenance and repair, and depreciation.

6 Business base considerations are important in determining the burdened costs because certain fixed costs (costs that occur independently of workload such as security costs) get spread to all the work. With a bigger base to spread these costs, the effect on the hourly rate is reduced.

Figure 3.3
Annual Direct and Burdened Labor Costs from a Select Set of Aircraft Programs, Fiscal Years 1969 to 2003



SOURCE: CCDRs.
RAND *MG696-3.3*

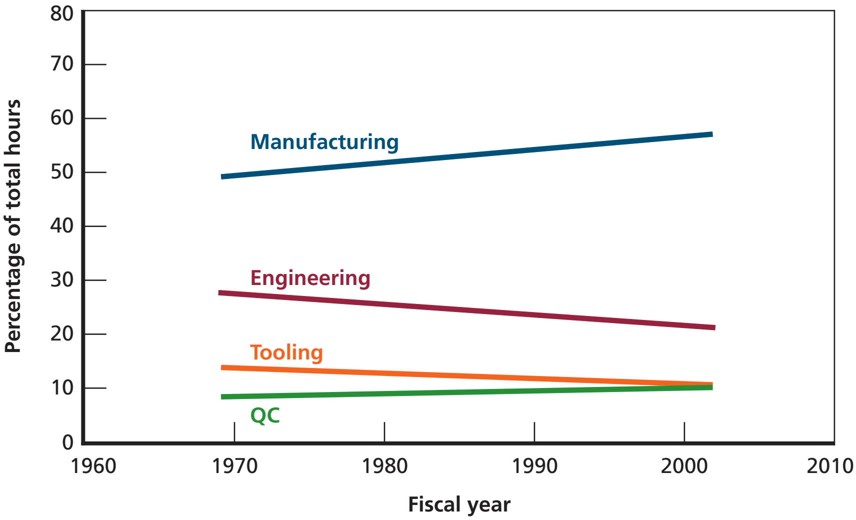
Table 3.2
Direct and Indirect Annual Escalation Rates for Labor Subcomponents, 1969 to 2003

Labor Subcomponent	Direct, %	Indirect, %
Engineering	5.7	6.2
Tooling	6.0	5.9
QC	5.6	5.3
Manufacturing	5.8	5.8

indirect, appears to be similar. In other words, growth in no one element appears to be driving increases in overall labor costs.

Another important issue is whether there has been a shift in the labor content; in other words, has there been a shift in the relative hours by labor subcomponent? Figure 3.4 shows trend lines (linear regressions) for the fraction of the labor hours by subcomponent. We

Figure 3.4
Percentage of Labor Hours by Subcomponent, 1969 to 2003



NOTE: Trends are not statistically different.
RAND *MG696-3.4*

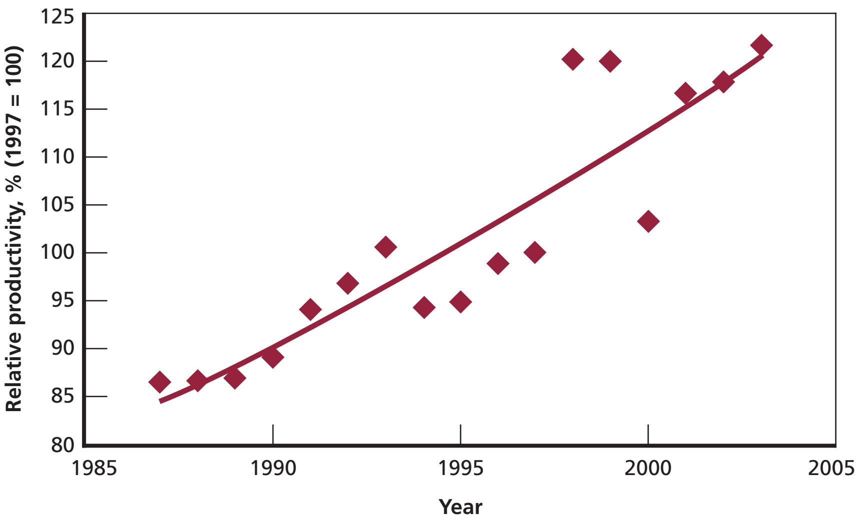
have omitted individual observations for clarity. None of the trends shown are statistically significant. This implies that there has not been an observable change in the labor ratios or a shifting of work between the labor types that could account for some change in direct rates. The average (and the associated standard deviation) for the distribution of hours for the time period shown has been

- manufacturing, 54 percent (15 percent)
- engineering, 25 percent (16 percent)
- tooling, 13 percent (7 percent)
- quality control, 9 percent (2 percent).[7]

Some reduction in the percentage of labor costs relative to those for equipment and material costs might be attributed to greater efficiency. Figure 3.5 shows the relative labor productivity (output per

[7] Numbers do not add to 100 percent because of rounding.

Figure 3.5
Aerospace Labor Productivity, 1987 to 2003



SOURCE: BLS.
RAND *MG696-3.5*

hour) as measured by the BLS in the aerospace sector from 1987 to 2003. The overall annual productivity increase is 2.2 percent per year. Note that the automotive industry in this timeframe saw an approximate 3.2 percent gain in productivity. Over the 16-year span, productivity in the aerospace sector increased by a total of about 40 percent. This gain in productivity helps to offset the increase in direct and indirect labor rates.

Material and Equipment

Material and equipment costs are the other two economic factors in aircraft cost growth. As was seen from the earlier split in Table 3.1, these two elements account for just over half of the weapon system cost for typical fixed-wing aircraft. Metals (e.g., aluminum, steel, titanium) or composites (e.g., carbon fiber, bismaleimide, and thermoplastics) are mainly used for the manufacture of the airframe (the aircraft's main

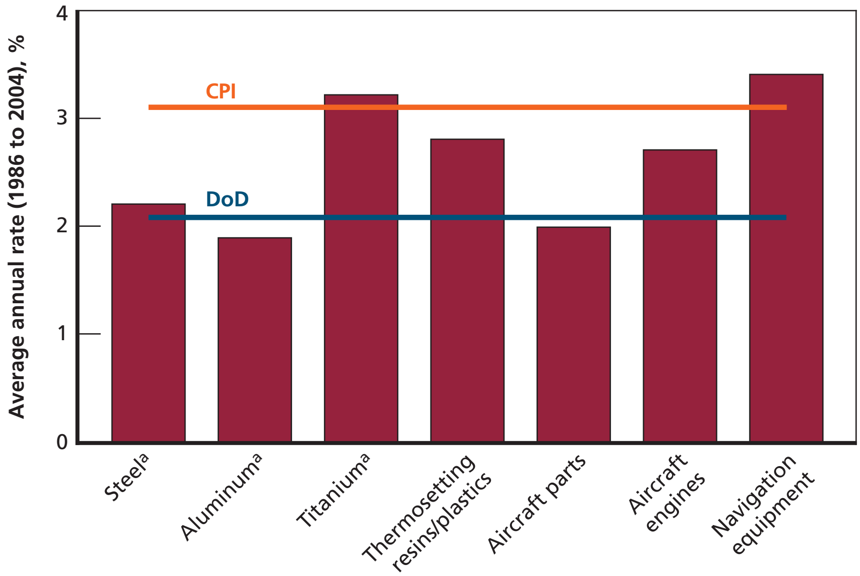
structure). Modern aircraft increasingly use high-strength, low-weight materials such as titanium and composites for improved performance. Composites have the added benefit of potentially reducing signatures (i.e., reducing the possibility of detection by sensors such as radar). Equipment comprises all systems such as avionics (electronics to control the aircraft), sensors (such as radar), other mission systems (such as electronic countermeasures, communications, targeting systems, guns, and missiles), and propulsion systems.

To understand how price changes in these materials and systems affect cost, we analyze the price escalation for several commodities from Producer Price Index (PPI) data collected by BLS. These include

- steel mill products—BLS Series ID WPU1017
- aluminum sheet, plate, and foil manufacture—BLS Series ID PCU331315331315
- titanium mill shapes—BLS Series ID WPU102505
- thermosetting resins and plastics materials—BLS Series ID PCU3252113252114
- other aircraft parts and auxiliary equipment manufacturing—BLS Series ID PCU336413336413
- aircraft engine and engine parts manufacturing—BLS Series ID PCU336412336412
- aeronautical, nautical, and navigational instruments, not sending/receiving radio—BLS Series ID PCU3345113345111.

Figure 3.6 shows the average compound growth rate for these seven components from 1986 through 2004. The horizontal lines depict growth in the CPI and the DoD procurement deflator during that same time. Growth for most of the components is above the DoD deflator but less than the CPI. Two components, those for navigation equipment and titanium prices, exceed growth for both comparison indices. These components do not reflect the recent price increases in metals experienced since 2004, including the 40 percent increase in the price of steel in 2004 and 2005 and the near doubling of the price of titanium between January 2005 and April 2006.

Figure 3.6
Material and Equipment Price Escalation, 1986 to 2004



[a]Trend does not include recent, dramatic price changes.
SOURCE: BLS.
RAND *MG696-3.6*

To determine indices for material, we use a weighted average of the first four PPI components in the list above for each aircraft. We base the weighting on the proportion of each material in the final weight of a typical airframe.[8] We recognize that the materials composition of fixed-wing aircraft has dramatically changed over the last few decades. Nevertheless, we see these changes driven by performance and requirements issues (not a substitution for economic reasons) because the customers' desire for performance has affected the choice of materials for airframes. In the next chapter, we address the cost implications of the shift toward more advanced, and expensive, materials. For an index of the cost escalation for equipment, we use a simple average of the last

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[8] Using final weight of material composition in the aircraft does not reflect production waste differences between material types and their associated manufacturing methods and scrap prices.

three PPI components. Table 3.3 shows the annual indexes for material and equipment.

Table 3.3
Material and Equipment Escalation Rates, 1986 to 2004

Factor	Annual Increase, %
Material	1.9 to 3.1
Equipment	2.6

NOTE: We present the possible range of values because the material escalation depends in large part on the material mix of the airframe.

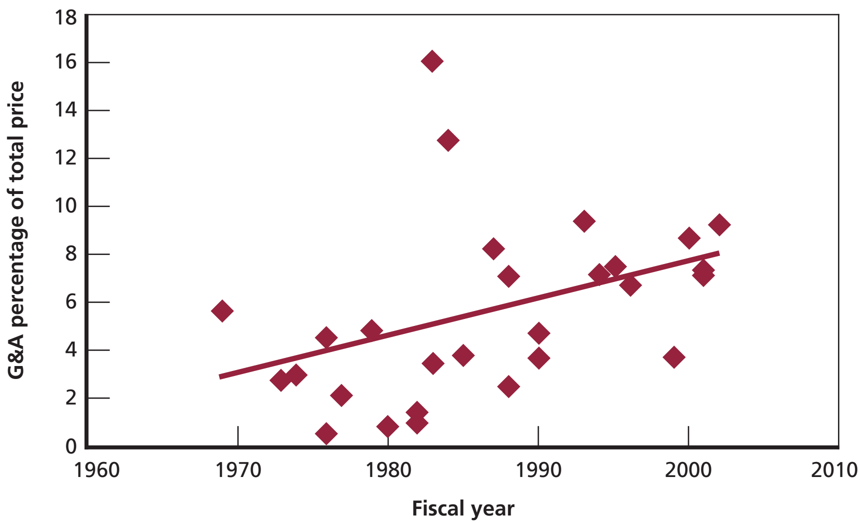
Fees and Profits

The final set of economy-driven factors that we examine is fees and profits. Although the government has some control on negotiating fee levels, it does not set market expectations for the firms or the level of return the companies must demonstrate to their shareholders. Rather, the marketplace sets a baseline level of return that must be ultimately reflected in profits that manufacturers earn. Similarly, there are allowable charges that the firms can bill the government. Three such charges are G&A costs, material overhead, and fees and profits. G&A is fairly consistently reported in the CCDRs, but material overhead and profit/fee are not. Below, we review trends in G&A, material overhead, and fees and profits for aircraft manufacturers.

General and Administrative Costs

G&A costs are allowable charges that cover general corporate expenses that cannot be attributed to a single program or contract. These costs typically cover expenses such as corporate management salaries and benefits, legal and accounting costs, and office supplies, as well as internal research and development (IR&D) and bid and proposal (B&P) costs. Figure 3.7 shows the fraction of G&A relative to total cost

Figure 3.7
G&A Percentage of Total Cost, by Fiscal Year, 1969 to 2003



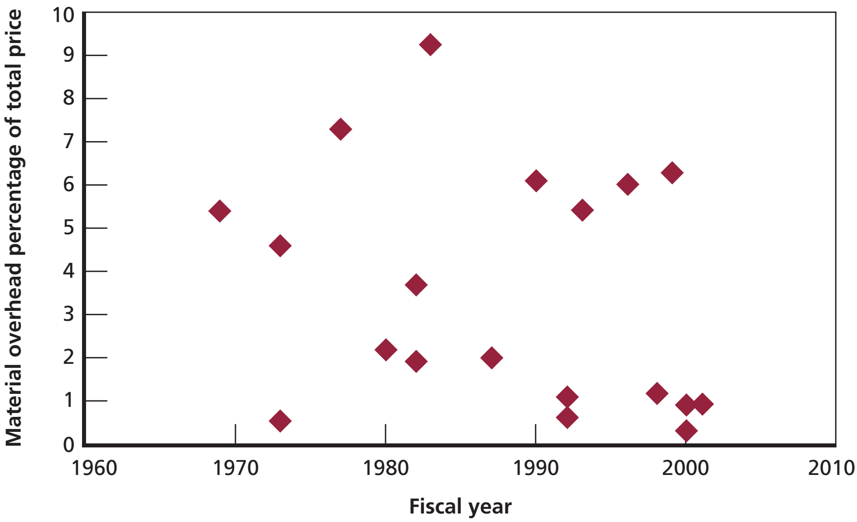
SOURCE: CCDRs.
RAND *MG696-3.7*

from the CCDRs for the 14 programs described above. Despite the variability, there is a clear and significant trend (>95 percent confidence), with the G&A proportion of total costs increasing approximately 0.2 percent per year.

Material Overhead

Material overhead covers activities such as handling, ordering, and storage costs for material and equipment purchased on a contract. Figure 3.8 shows trends in material overhead cost relative to total cost from the CCDRs for the 14 programs described above. Note that the trend line is not significant because of the high variability of the data. This variability is due to how material activities are charged on a contract—sometimes as a direct charge, sometimes in general overhead, and sometimes as an explicit fee. Typically material overhead is about 3 percent of total aircraft costs.

Figure 3.8
Material Overhead Percentage, by Fiscal Year, 1969 to 2003



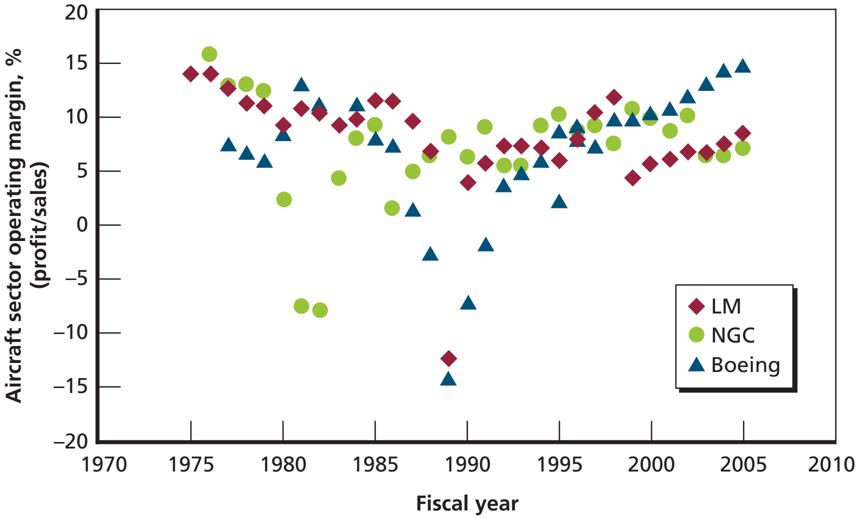
RAND *MG696-3.8*

Fees and Profits

Fee and profit levels are often inconsistently reported or not reported at all in the CCDRs. To assess whether these costs have changed over time, we use the annual reports (10-Ks) for the three major U.S. military aircraft manufacturers—Boeing, Lockheed Martin (LM), and Northrop Grumman Corporation (NGC)—and data on operating margins in their defense aircraft sector. These reports are publicly available on company or Securities and Exchange Commission (SEC) Web sites. Operating margin is the ratio of overall profit to sales and does not directly correspond to profit earned on any particular contract. For example, other sector expenses or investments might offset the total profit earned on individual contracts.

Analyzing trends in operating margins for these firms is difficult because of the many reorganizations and mergers they have undergone in recent decades. Nevertheless, such data are the best data publicly available. Figure 3.9 displays trends in operating margins over time.

Figure 3.9
Operating Margin for Aircraft Sector, by Year, 1975 to 2005



SOURCE: Company annual reports.
RAND *MG696-3.9*

The data are highly variable, particularly in the late 1980s. After 1995, the operating margins stay within a band of approximately 5 to 15 percent. This narrow range might be a reflection of the way DoD negotiates profit levels.

Although operating margins for all three manufacturers have fluctuated over time, there is no discernable, consistent trend to be seen. Rather, operating margins have generally remained between 5 and 15 percent of total sales.

Notional Aircraft Comparisons

How much does each economic factor that we have reviewed contribute to the total annual rate of increase in the price of fixed-wing aircraft? The answer depends to a certain extent on the characteristics of the aircraft (e.g., the labor/material/equipment split, the materials of construction) and the timeframe. For illustration, we will use a notional

comparison of an aircraft built in 1980 and the same aircraft built in 2000. We assume that the material distribution for this notional aircraft is 55 percent aluminum, 10 percent steel, 30 percent titanium, and 5 percent composites. Our analysis approach uses a weighted price index based on the component indexes (i.e., labor, material, and equipment) described above.[9] Table 3.4 lists the contributions of the economic factors for this example. The total for all the factors is 3.5 percent. In comparison, the CPI rate of increase was approximately 3.8 percent and the DoD procurement deflator was 3.3 percent. Thus, the overall growth resulting from the individual economic factors for this notional example was similar to the other measures of inflation.

Table 3.4
Contributions of the Economic Factors to Cost Escalation for a Notional Example

Economic Factor	Contribution to Annual Rate of Increase, %
Labor	0.8
Material	1.3
Equipment	1.1
Fees and profits	0.2
Total	3.5

Summary

In this chapter, we have explored the contribution of economy-driven factors—that is, those largely outside the direct control of the Services—to cost growth for aircraft. Although we found that labor costs (both direct and indirect) grew at a rate greater than other measures of inflation, we also saw that gains in productivity offset these increases. Materials and equipment costs grew at a rate at or below these same

[9] The approach is analogous to the way the inflation is constructed using component indexes. Here we use the percentage of value as our weighting factors. For more information on weighted price indexes, see, for example, Schultze and Mackie (2002) or Statistics Canada (1995).

measures of inflation. For a notional example, the overall rate of growth resulting from the individual economy-driven factors was 3.5 percent, a rate of increase similar to that for the CPI and DoD deflator in the same period of time. Our notional example, however, assumed that an identical aircraft was being purchased over time. Undoubtedly, the complexity and quality of the aircraft (e.g., its performance and effectiveness) that the Services have purchased have increased over time. In the next chapter, we explore the price implications of the demand for more complex aircraft.

CHAPTER FOUR

Customer-Driven Factors

Although the Services cannot influence many of the elements that work to set aircraft prices, they are, of course, responsible in at least two ways for the amount of money they spend on aircraft. First, the Services decide on the number of aircraft they wish to purchase. Second, they determine the characteristics they want these aircraft to have. Although the number and characteristics of aircraft may be determined by threats to the nation that the Services must address, it is still true that the Services can influence these variables more than economy-driven ones affecting price. We examine these customer-driven variables in this chapter.

For the analysis in this chapter, all unit costs are adjusted to fiscal year 2006 dollars using APN procurement deflators. Inflation adjustment is critical because the effects of inflation itself are accounted for in our previous analyses of the economy-driven factors of labor, equipment, and material.

Quantity Effects

The quantity of aircraft that the Services procure can affect aircraft cost in two different but related ways. First, additional quantities ordered over time can have a cost improvement effect, in which accumulated experience in producing the same system year after year helps to reduce its unit cost. Second, the quantity ordered in any given year has a procurement rate effect that results from changing the lot size of the same system from one year to the next, with high procurement rates helping

to reduce unit cost through greater operating efficiency and the spreading of fixed costs over more units.

Confounding these quantity effects are the influences of configuration changes. A configuration change is a *series* change in the production design (e.g., from F/A-18A/B to F/A-18C/D). Such a change may disrupt production to the point that some quantity effects are altered or masked through increased cost. We will explore how this series change effect modifies the quantity effects by directly accounting for the sequence of series variants. (For example, for the F/A-18 model, we consider the A/B, C/D, and E/F variants as one linked program and look at the effect on the cost of each series change).

Cost Improvement

The cost improvement (CI) effect means that the effort and expenditure required to produce an aircraft will decrease as the number of aircraft produced increases. More generally, it can be expressed as the effect of learning-by-doing on aircraft cost. Mathematically, the cost improvement effect can be expressed as

$$C_t = C_1 \times n_t^{\ln(\text{CI slope})/\ln(2)} \tag{4.1}$$

where

- C_t is the cost of the unit at the midpoint of annual buy t
- C_1 is the cost of the first unit
- n_t is the unit number of the midpoint[1] of annual buy t
- CI slope is the unit cost improvement slope.

[1] For technical reasons, the midpoint of the first annual buy is assumed to be reached after one-third of the total units for the first annual buy have been procured. For subsequent lots, the midpoint is assumed to be reached when one-half of the total units in an anual buy have been procured.

For Equation 4.1, we have used a lot midpoint formulation because our cost data are a lot average only; we do not have cost by individual aircraft tails.[2]

We assessed Equation 4.1 for each aircraft, many of which had production runs of three or four continuous annual buys. Table 4.1 presents regression equation results depicting the cost improvement effect as a function of the minimum number of annual buys of the aircraft. Scaling by number of annual buys is important because fewer annual buys mean fewer data points in Equation 4.1, yielding potentially unreliable results. Table 4.1 shows that the mean and median cost improvement slope, and hence the cost improvement effect, is modest—only a few percent—and does not substantially depend on the number of annual buys. It shows that for programs with at least five annual procurements—for which there were 52 aircraft systems—every doubling of aircraft unit number leads to a unit cost decrease averaging 3 percent.[3]

Notice also that for programs with at least six annual buys, there is essentially no average cost improvement.[4] This does not mean that cost improvement is nonexistent. On the contrary, the standard

Table 4.1
Cost Improvement Slopes, by Minimum Number of Annual Buys

	Minimum Number of Annual Buys			
	3	4	5	6
Mean CI slope	0.98	0.95	0.97	0.99
Median CI slope	0.97	0.94	0.97	1.00
Standard deviation CI slope	0.18	0.15	0.15	0.14
Number of aircraft systems	98	64	52	37

2 Readers requiring either an introduction or a detailed explication of learning curve analysis chould consult Goldberg and Touw (2003).

3 A CI slope 0.97 implies that moving from the first to the second unit reduces unit cost by 3 percent (1 – 0.97 = 0.03). A further 3 percent reduction is also seen in the fourth unit, compared with the second unit, etc.

4 Mean, median, and standard deviations change little with minimum number of annual buys greater than six.

deviation of 0.14 shows that some systems have cost improvement slopes much lower than one. Nevertheless, this also does show that some systems have cost improvement much greater than one or experienced price increases as the number of annual buys increased.

Procurement Rate

Procurement rates may have positive or negative effects on unit price. A high procurement rate, for example, can help spread fixed overhead costs over more aircraft, thus reducing the average unit cost. Higher procurement rates may result in greater and more efficient use of existing plant and tooling, also helping to reduce unit costs. Higher procurement rates may also lead to more efficient use of labor through specialization. Other variables, such as increases in total costs caused by unforeseen supplier problems, unexpected labor and materials costs, or failures in implementing new technologies, could lead to higher costs, which, in turn, could lead to the government cutting procurement rates.

Mathematically, the combination of cost improvement and procurement rate effects can be stated as

$$C_t = C_1 \times n_t^{\ln(\text{CI slope})/\ln(2)} \times r_t^{\ln(\text{PR slope})/\ln(2)} \tag{4.2}$$

where

- C_t is the cost of the unit at the midpoint of annual buy t
- C_1 is the cost of the first unit
- n_t is the unit number of the midpoint of annual buy t
- CI slope is the unit cost improvement slope
- r_t is the number of units procured in annual buy t
- PR slope is the procurement rate slope.

Again, we have used the lot midpoint formulation as our cost data are by lot and not unit. Cost improvement and procurement rate effects are estimated for all systems in the HAPCA and P-1 databases; the constants C1, CI slope, and PR slope are uniquely estimated for all systems.

Equation 4.2 looks and functions like Equation 4.1. The additional procurement rate slope term can be interpreted just like the cost improvement slope: A doubling of the procurement rate leads to a 1 – PR slope percentage change in average cost.

Yet, there are several complications with this formulation. Some of these complications force us to restrict the systems under consideration. Others require that we make arbitrary methodological decisions that could change the results of the analysis. First, many systems have limited production runs, but Equation 4.2 cannot be used for systems with fewer than four fiscal year purchases. Of the 178 Navy and Air Force fixed-wing aircraft systems (including variants) in the combined P-1 and HAPCA database, only 52 have at least five fiscal year buys. Second, midpoint quantity and procurement rates tend to be highly correlated, especially among systems with short production runs. Because this correlation can lead to statistically misleading results, systems with midpoint and lot size correlations greater than the absolute value of 0.6 are excluded in the final analysis of cost improvement and procurement rate effects.[5] These restrictions reduce the number of systems that can be analyzed from 52 to 24.

The restricted data still include a diverse array of Air Force and Navy programs over the past 50 years, including attack, cargo, electronic, patrol, and training aircraft, but no bombers. Table 4.2 shows

Table 4.2
Cost Improvement and Production Rate Slopes, by Minimum Number of Annual Buys

	Minimum Number of Annual Buys					
	5	6	7	8	9	10
Average CI slope	0.97	0.98	0.98	0.99	0.99	0.99
Standard deviation in CI slope	0.13	0.14	0.14	0.14	0.16	0.16
Average PR slope	0.90	0.88	0.88	0.86	0.83	0.80
Standard deviation in PR slope	0.23	0.15	0.15	0.15	0.16	0.14
Number of aircraft systems	24	14	14	12	9	8

5 For example, the F/A-18 series A/B, C/D, and E/F are excluded from this analyis because of the high degree of correlation between midpoint and lot size.

the results of applying Equation 4.2 to these systems and how cost improvement and procurement rate vary by minimum number of years in which systems are purchased.

Table 4.3 shows average cost improvement and procurement rate slopes by aircraft type and by service, along with minimum and maximum slope evident among individual systems we consider.

With and without adjusting for procurement rate effects, there is little to no cost improvement on average: Slopes center on 96 percent (Table 4.3) to 97 percent (Table 4.1). Cost improvement slopes range from 74 percent for C-9 to 139 percent for C-130H, with an overall average of 96 percent; it is notable that these extremes are in the same category that on average have almost no CI effect: cargo aircraft. On average, attack, fighter, cargo, and training aircraft have cost improvement slopes less than one, meaning that unit costs become cheaper as unit number increases, whereas electronic and patrol aircraft have cost improvement slopes greater than one, meaning that unit costs actually rise as unit number increases.

Table 4.3
Cost Improvement and Production Rate Slopes with a Minimum of Five Annual Buys

	CI Slope	PR Slope
Attack	0.91	0.87
Cargo	0.99	1.08
Fighter	0.93	0.78
Electronic	1.09	0.73
Patrol	1.09	1.04
Trainer	0.97	0.91
Minimum	0.74	0.61
Mean	0.96	0.89
Maximum	1.39	1.75
Navy mean	0.94	0.87
Air Force mean	1.01	0.94

Procurement rate slopes range from 0.61 for F-15E to 1.75 for C-37, with an overall average of 0.89. This means that, on average, a doubling of annual procurement quantity yields an 11 percent decrease in unit cost. Also, Air Force systems have a 7 percent higher cost improvement slope and 7 percent higher procurement rate slope than Navy systems. These differences are almost fully explained by the pull of extreme cargo aircraft observations: a C-130H CI slope of 1.38, and a C-37 PR slope of 1.75. Without these two data points, the Air Force would generally have lower cost improvement and procurement rate slopes than the Navy.

In determining average cost improvement curve and procurement rate effects, we chose to mix the results of regressions without weighting by their statistical significance. In general, smaller production runs will yield less statistically significant results, even though the substantive underlying relationship is present. Yet, we found surprisingly little difference between cost improvement and procurement rate slopes in data samples that included or excluded small production runs. We also found minimal correlation between these slopes and no evident trend over time for them.

Configuration Effects

It is possible that separating a single aircraft model into its component series for quantity analyses neglects the cost consequences of a shared development and production environment.[6] We therefore analyze cost improvement and production rate slope effects within a single model by specifically incorporating configuration (series change) effects in our regression analysis.

Only a few aircraft systems have long-term continuous production of well-defined configuration upgrades. In addition to the well-known cases of the F-14, F-15, F-16, and F-18 fighters, the NAVAIR database contains the older but still relevant AV-8B Harrier II, F-4, A-6, and P-3

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[6] Here, a "series change" means modifying a number of components of an already existing and successful aircraft, such as the modification needed to make the F-16A/B into the F-16C/D. This modification process is usually far cheaper than a "blank-sheet" design of a new airframe, with new avionics and propulsion.

programs. Table 4.4 lists all configurations for the aircraft and the year they were implemented. Of all the aircraft considered in this subsection, only the F/A-18 is not included in our analyses above on cost improvement and procurement rate effects (because of correlation issues).

We analyze configuration effects with the following equation:

$$C_t = C_1 \times n_t^{\ln(\text{CI slope})/\ln(2)} \times r_t^{\ln(\text{PR slope})/\ln(2)} \times \exp(d_1 * CC_{1,t} + d_2 * CC_{2,t}) \quad (4.3)$$

where

- C_t is the cost of the unit at the midpoint of annual buy t
- C_1 is the cost of the first unit
- n_t is the unit number of the midpoint of annual buy t
- CI slope is the unit cost improvement slope
- r_t is the number of units procured in annual buy t
- PR slope is the procurement rate slope
- d_1 is the first configuration change coefficient
- $CC_{1,t}$ is the dummy variable for the first configuration change
- d_2 is the second configuration change coefficient
- $CC_{2,t}$ is the dummy variable for the second configuration change.

Table 4.4
Aircraft Models' Long-Term Production Profiles and Dates of Configuration Change

Model	Service	Original Configuration		Second Configuration		Third Configuration	
A-6	Navy	A-6A	1959	A-6E	1970		
AV-8B	Navy	AV-8B	1982	AV-8B NAA	1988	AV-8B RAD	1991
F-14	Navy	F-14A	1971	F-14A+	1986	F-14D	1988
F-15	Air Force	F-15A/B	<1974	F-15C/D	1979	F-15E	1988
F-16	Air Force	F-16A/B	1978	F-16C/D	1983		
F-4	Navy	F-4A	1955	F-4B	1960	F-4J	1965
F/A-18	Navy	F/A-18A	1979	F-18C/D	1986	F/A-18E/F	1997
P-3	Navy	P-3A	1961	P-3B	1965	P-3C	1968

The configuration change variables indicate whether a procurement lot has progressed to the next redesign or improvement in technology. A lot has a value of 1 if the system produced in that lot has progressed to the next series, 0 if it has not. The configuration change coefficients should indicate an increase in the cost of the system compared to the original configuration. In Equation 4.3, the configuration change variables work to increase or decrease $\ln(C_1)$, the constant.

In Table 4.5, we compare the calculated cost improvement and procurement rate coefficients using Equation 4.3 with configuration change terms to those calculations using Equation 4.2. The aggregate result indicates that explicitly modeling configuration change has little substantive effect on the values for the cost improvement or procurement rate slopes as shown in the values of Table 4.5. Thus, the fact that we did not account for configuration changes in our earlier cost improvement and procurement rate analysis did not influence our results.

For each aircraft in Table 4.5, the leftmost column shows the system name. The “CI Slope” column contains the estimate for CI slope not accounting for configuration change; the “CI Slope with CC” column contains the estimate for CI slope accounting for configuration change. The next two columns contain PR slopes without and then with configuration change taken into account. The next column contains the correlation between lot midpoint unit number and the number of units procured in that lot. The last two columns contain the configuration change coefficients: CC1 for the first configuration change, CC2 for the second configuration change.

In the results including configuration change effects, the F-4 shows the highest correlation between cost improvement and procurement rate, 0.66. This high correlation calls into question the statistical validity of the values for the F-4. We therefore present the mean values with and without this observation included in the sample. Including configuration change apparently has little to no effect on the mean CI or PR slopes of the remaining seven programs. Including configuration change effects results in

Table 4.5
Results of Regression Incorporating Configuration Change (CC) Effects

System	CI Slope	CI Slope with CC	PR Slope	PR Slope with CC	Correlation Between CI and PR	CC1 Slope	CC2 Slope
A-6	0.88	0.86	0.71	0.73	0.10	1.13	
AV-8B	0.85	0.86	0.72	0.71	0.14	0.97	0.98
F-14	0.94	0.93	0.77	0.80	–0.43	0.97	1.29
F-15	0.97	1.18	0.66	0.62	–0.51	0.60	0.49
F-16	0.99	0.91	0.94	0.94	–0.46	1.45	
F-4	0.81	0.72	0.86	0.86	0.66	1.21	3.48
F/A-18	0.98	0.91	0.83	0.87	0.07	0.95	2.02
P-3	1.05	1.02	0.68	0.76	–0.41	0.77	1.28
Mean (all)	0.93	0.92	0.77	0.79		1.00	1.59
Mean (without F-4)	0.95	0.95	0.76	0.78		0.98	0.87

- little to no change in cost improvement or procurement rate slopes for the A-6, AV-8B, and F-14 aircraft
- a slight increase in the cost improvement slopes but no effect on the procurement rate slopes for F-16 and F-4 aircraft
- a flattening of the cost improvement slope but a steepening of the procurement rate slope for P-3 aircraft
- a reversal of the cost improvement slope for F-15 aircraft, with a negative cost improvement (CI > 1) slope but a persisting steep procurement rate effect.

The configuration change coefficients, CC1 and CC2, are multipliers of average unit cost.[7] They are mathematically very simple effects, but their meaning must be interpreted with great caution. For example, these equations show that, taking into account CI and PR effects, the third configuration F-15 is 51 percent less expensive than the original configuration (or 1, representing the original configuration, less 0.49, representing the CC2 slope for the third configuration, or 0.51 x 100 percent). But historical costs for the F-15 actually rose 10 percent from

7 CC1 slope and CC2 slope are defined as e^{CC1} and e^{CC2}, respectively.

the last lot of the original configuration to the first lot of the third configuration. One can understand the intuition behind Equation 4.3 and configuration effects by considering CI effects, PR effects, and CC effects together for a specific lot-to-lot comparison.

At the end of the initial configuration, roughly 500 F-15A/B had been produced, and by the beginning of the third configuration, nearly 950 F-15A/B/C/D had been produced. Hence, at a 1.18 slope, CI effects should have increased unit costs by 17 percent.[8] And the average production rate starting the third configuration (42) was 58 percent less than the production rate ending the original configuration (97); at a 0.62 slope, PR effects should have increased unit costs by 78 percent.[9] Yet actual unit costs rose by 10 percent, meaning that another effect (configuration change) could be counteracting the CI and PR effects. A configuration change slope of 0.49 implies a 51 percent decrease in unit cost as a result of the configuration change. Multiplying these factors together as seen in Equation 4.3 yields 1.17 × 1.78 × 0.49 = 1.02; that is, in this case, there was a large configuration effect bringing costs down that nearly balanced the cost-increasing CI and PR effects. The difference between the predicted cost increase of 2 percent and the actual cost increase of 10 percent is due to statistical error.

For all seven programs within correlation bounds (i.e., those for which the correlation between lot midpoint unit number and the number of units procured in that lot is less than the absolute value of 0.6), the first configuration change has virtually no effect on cost. This is shown in Table 4.5 by the mean 0.98 CC1 slope for these programs. The second configuration change leads to a 13 percent decrease in cost, after controlling for cost improvement and production rate effects. This is shown in the 0.87 mean for the CC2 slope among the five remaining programs within correlation bounds that had at least two configuration changes.

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8 Equation 4.3 contains $n_t^{\ln(\text{CI slope})/\ln(2)}$. We calculate 17 percent by dividing $950^{\ln(1.18)/\ln(2)}$ by $500^{\ln(1.18)/\ln(2)}$ then subtracting 1.

9 Equation 4.3 contains $r_t^{\ln(\text{PR slope})/\ln(2)}$. We calculate 78 percent by dividing $42^{\ln(0.62)/\ln(2)}$ by $97^{\ln(0.62)/\ln(2)}$ then subtracting 1.

Basic Technical Characteristics

In addition to assessing learning curve and production rate effects, we used our technical database to determine how several aircraft-specific performance variables affect average unit cost over the entire program. These variables include service, personnel complement, ceiling, range, airframe weight, thrust (or horsepower), cruising speed, maximum speed, mission of aircraft, and whether it is carrier-based.

For this analysis, we first identified variables that are highly correlated with average unit cost. We then identified the subset of variables with high explanatory power, that is, large, statistically significant regression coefficients but little correlation with one another.

The final set of variables—empty weight, maximum speed, whether an aircraft is carrier based, whether the aircraft is electronic, and whether the aircraft is a bomber—are shown in Table 4.6. We analyzed them using the following equation:

$$C = K \times EW^{a} \times MS^{b} \times CarrierBased^{c} \times Electronic^{d} \times Bomber^{e} \quad (4.4)$$

where

- C is the average unit cost of an aircraft system
- K is a constant
- EW is the empty weight of the aircraft
- MS is the maximum speed of the aircraft
- CarrierBased is a dummy variable for carrier-based aircraft
- Electronic is a dummy variable for electronic aircraft
- Bomber is a dummy variable for bomber aircraft
- a, b, c, d, and e are the coefficients of the EW, MS, CarrierBased, Electronic, and Bomber variables.

The parameter values of Table 4.6 help us to understand some of the technical drivers of aircraft unit cost. For example, a larger aircraft (all other things being equal) costs more than a smaller one. Not only is this a reflection of having to build a larger airframe but also of more expensive systems that are put onboard. Notice, however, that the scaling

Table 4.6
Results of Regressions on Technical Characteristics

	Parameter	Standard Error	t Statistic	p Value
ln (empty weight)	0.91	0.08	11.54	<0.0001
ln (max speed)	0.83	0.14	5.75	<0.0001
Carrier based	0.38	0.17	2.27	0.0256
Electronic aircraft	1.01	0.25	4.06	0.0001
Bomber aircraft	1.14	0.35	3.21	0.0018
Intercept	–11.83	1.20	–9.86	<0.0001

is less than one. In other words, an aircraft twice as big does not cost twice as much—it costs 1.88 (2^ 0.91) times as much. Carrier-based aircraft cost more than land-based ones. This difference is likely due to the more extreme operating environment (e.g., arrested landings and sea environment) that these aircraft face. Electronic aircraft (e.g., P-3, E-2C, and AWACS cost more than other aircraft types of similar performance. This difference is due to the additional mission equipment that these aircraft have. The bomber parameter is driven by the B-2, for which stealth was an emphasized capability.

These variables help us to assess the relationship between the airframe design and propulsion aspects of the aircraft but do not address the internal complexity of its airframe. The complexity of the airframe can be assessed by quantifying its type of materials. The metric we use, labeled "simple," is the share of airframe structure that is neither titanium nor composite material. Unfortunately, only 49 of the 93 aircraft with complete data on basic technical characteristics have available data on material composition. To retain as many observations as possible for analysis, we regressed basic technical characteristics on 93 aircraft as in Equation 3.4. The residuals of 49 of those (denoted in Appendix A) are used as the dependent variable to assess the cost effects of materials composition. Mathematically, this yielded

$$R^* = K \times \text{Simple}^a \tag{4.5}$$

where

- R* are the residuals of regression for Equation 4.4
- Simple is the fractional share of airframe structure that is neither composite nor titanium
- a is the coefficient for the Simple variable.

Table 4.7 presents the results of these regressions. The –1.42 coefficient of Simple indicates that as titanium and composite materials increase as a proportion of airframe materials (or as simpler materials decrease), aircraft unit cost increases. Increasing the proportion of titanium and composite materials in an airframe from 0 to 5 percent costs a 7 percent premium, whereas increasing them from 40 to 45 percent costs a 13 percent premium.[10]

Table 4.7
Results of Regressions on Airframe Materials Complexity

Parameter	Value	Standard Error	T Statistic	P Value
a	–1.42	0.43	–3.31	0.0014
ln(K)	6.51	1.92	3.39	0.0014

Other Elements

Our analyses do not account for changes in avionics complexity, software implementation, operating and support costs, and longevity. Metrics such as avionics power, weight, or lines of code could serve as proxies for avionics complexity. Mean time between shop visit could serve as a proxy for operating and support costs. The number of landings or flying hours permitted between major overhauls could serve as a proxy for longevity. Data for these variables, however, are available for only the most recent systems—and are not even applicable to the oldest systems in our database. Even with sufficient information on these variables, it is unlikely that the limited number of observations would provide clear results.

[10] According to Equation 4.5, cost is proportional to Simple^{a}. Seven percent is derived from $95^{-1.42}/100^{-1.42}$. Thirteen percent is derived from $55^{1.42}/60^{-1.42}$.

Summary

In this chapter, we have explored the contribution of customer-driven factors that are in the direct control of the Services. We found that technical characteristics (such as airframe weight, maximum speed, and materials composition) correlate very strongly with unit price, suggesting that technical complexity is a major driver within the customer-driven factors. We also explored cost improvement and production rate effects. The cost improvement effect was highly variable, and we observed no general or consistent trends. On the other hand, production rate did show a consistent effect in that the average unit price was lower for increased production rate. In the next chapter, we explore the relative importance of all the customer and economic factors by comparing the difference between pairs of aircraft.

CHAPTER FIVE

Pairwise Comparisons

In this chapter, we analyze both economy-driven and customer-driven factors together by comparing aircraft systems recently procured with same-mission, previous-generation aircraft procured decades ago. These pairwise comparisons are necessary to complete our analysis. Cost escalation measured between two systems may be attributable to differing economic environment and customer choices for each aircraft being procured. Without picking one aircraft in the past and one in the present, there is no way to quantitatively explain cost escalation.

We selected eight aircraft pairs for the comparison, at least one example from each mission type. Where possible, we chose examples from both Services. Finally, we also chose pairs that spanned the greatest period of time and technical change. For example, we compare the F-15A to the F-22A rather than the F-15C/D to the F-16C/D. Obviously, many such combinations were possible. The pairs selected are representative, only.

We will explain differences in cost escalation between comparisons by specifying the characteristics of each aircraft in comparison pairs and accounting for economy- and customer-driven factors. Among the individual economy-driven factors we consider are labor, material, and equipment. Individual customer-driven factors we consider are those relating to technical characteristics, airframe complexity, and production rate. Once these are determined, we aggregate and summarize the effects of both types of factors on cost escalation and compare them with actual escalation.

Economy-Driven Factors

Table 5.1[1] presents the effects of individual economy-driven factors on the eight aircraft pairs. For each pair, we present labor, material, and equipment escalation as well as G&A escalation as calculated in Chapter Three.

As noted in Chapter Three, labor costs have increased at a rate greater than inflation but, until recently, material and equipment costs have increased somewhat less so. Nevertheless, as also noted above, productivity improvements in aircraft manufacturing and outsourcing practices have reduced the proportion of costs attributable to labor. In 1970, material and equipment represented 45 percent of the cost of an aircraft; in 2005, they represented 62 percent. How much of cost escalation can these three factors explain?

For each pairwise comparison, we estimated each economy-driven factor by examining how representative indices (as identified in Chapter Three) changed over the time period in question, after weighting each by that factor's percentage of total cost. (Analysis of CCDRs generated annual estimates of the share of cost attributable to labor,

Table 5.1
Percentage Contributions to Annual Cost Escalation, by Economy-Driven Factors

Comparison	Labor	Material	Equipment	G&A	Total
F-15A (1975) to F-22A (2005)	0.8	1.6	1.0	0.2	3.5
F/A-18A/B (1983) to F/A-18E/F (2003)	0.8	1.0	1.1	0.2	3.1
B-1B (1984) to B-2A (1993)	0.9	0.9	1.1	0.2	3.1
C-130H (1980) to C-17 (2005)	0.8	1.3	1.0	0.2	3.2
E-3A (1975) to E-8C (2005)	0.8	1.4	1.0	0.2	3.4
E-2C (1975) to E-2C (2004)	0.8	1.5	1.0	0.2	3.4
T-34C (1978) to T-6A (2001)	0.8	1.3	1.0	0.2	3.3
T-34C (1978) to T-45TS (2000)	0.8	1.4	1.0	0.2	3.3

1 Note that rows of tables in this chapter may not sum to the total values presented because of rounding.

material, and equipment.) For example, in 1975, labor's share of total aircraft cost was calculated to be 52.3 percent.

In other words, out of the individual indices for labor, material, and equipment, we create a composite cost index for each aircraft of the pair. This composite index depends on the year procured and the specific materials used in an aircraft. We determine the composite price index by weighting the individual labor, material, and equipment indices by their shares of total aircraft cost. We then use the resulting composite index values to compute the overall annual cost escalation using Equation 2.1. The component contributions to annual cost escalation (i.e., the values shown for labor, material, and equipment) were based on the ratio of each component's annual percentage increases relative to the overall total.

Of the three economy-driven factors, material contributes the most to aircraft cost escalation, from 0.9 to 1.6 percent by the pairs we consider. Equipment had the second biggest influence, ranging from 1.0 to 1.1 percent, followed by labor, whose effects ranged from 0.8 to 0.9 percent. All three combined resulted in cost growth of 2.9 to 3.3 percent, or only a fraction of the 7 to 12 percent cost growth evident in the aircraft we examine.

Customer-Driven Factors

We next examine how customer-driven factors contribute to overall aircraft cost escalation in Table 5.2. Customer-driven factors include such items as the technical characteristics and use of advanced materials that we analyzed in Chapter Four. We calculate the customer-driven contributions to total cost escalation differently from our calculations of economy-driven contributions to total cost escalation. Rather than using changes in representative cost indices, we employ the scaling factors derived in the previous chapter to understand how unit cost should have changed. We examined how changes in empty weight, maximum speed, carrier-based, airframe materials complexity, and production rate should have influenced the average annual cost escalation. For example, if the maximum speed increased by 20 percent from one air-

craft to another, the results in Table 4.6 indicate that the average unit cost should increase by 16 percent (1.2^ 0.83 – 1). Again, the reader is cautioned that the technical complexity measures are *associative* and not necessarily *causal*. Other factors could influence aircraft cost, but the terms we have identified in Chapter Four have the strongest statistical relationship.

In Table 5.2, we have also included a term called regulatory factors. This factor of 0.6 percent is based on a 1998 proprietary analysis by the Electric Boat Division of General Dynamics Corporation that examined the changes in construction hours for four classes of submarines from the late 1960s through the current Virginia class. That approach categorized changes in the construction hours into several areas: technical advancement (e.g., performance improvements), weapon systems (e.g., number and complexity of systems), stealth characteristics (e.g., signatures), survivability, quality assurance, oversight control (e.g., reporting requirements), and regulatory environment (e.g., environmental protection laws). For the regulatory factor shown in Table 5.2, we selected only those areas that were broadly applicable to defense manufacturing, i.e., oversight control and regulatory environment—in other words, general changes to the manufacturing environment driven by the government (although not necessarily by

Table 5.2
Percentage Contributions to Annual Cost Escalation, by Customer-Driven Factors

Comparison	Technical Character-istics	Airframe Com-plexity	Procure-ment Rate	Regula-tory	Total
F-15A (1975) to F-22A (2005)	0.6	4.3	0.9	0.6	6.4
F/A-18A/B (1983) to F/A-18E/F (2003)	–0.1	2.1	0.5	0.6	3.1
B-1B (1984) to B-2A (1993)	–5.0	6.1	1.7	0.6	3.5
C-130H (1980) to C-17 (2005)	5.9	1.1	–0.5	0.6	7.1
E-3A (1975) to E-8C (2005)	0.6	0.0	1.1	0.6	2.3
E-2C (1975) to E-2C (2004)	0.3	0.3	0.6	0.6	1.9
T-34C (1978) to T-6A (2001)	2.9	0.0	–0.4	0.6	3.1
T-34C (1978) to T-45TS (2000)	10.5	0.1	0.6	0.6	11.9

one of the Services). Despite the study being focused on submarine issues, these changes to the general manufacturing environment should be similar. We converted the values reported in the study to an annual rate using Equation 2.1.

The contributions to annual cost escalation seen in Table 5.2 are based on cost indices for each aircraft of the pair using Equations 4.2, 4.4, and 4.5 (and their associated parameters listed in Chapter Four). The annual cost escalation for Technical Characteristics is based on Equation 4.4. The Airframe Complexity component is based on Equation 4.5. The annual cost escalation due to procurement rate changes is based on Equation 4.2. Again, the ratio of the index values was converted to an annual rate using Equation 2.1.

The contributions of customer-driven factors to cost escalation range considerably by comparison—as one might expect given the variety of aircraft and the different system histories. The technical characteristics resulted in a –5.0 percent contribution to cost de-escalation for the B-1B and B-2A bomber comparison[2] but a 10.5 percent increase for the T-34 to T-45 comparison. Procurement rate factors—a direct consequence of annual buy decisions—range from –0.5 percent for the C-130H and C-17 cargo plane comparison to 1.7 percent for the bomber comparison. Airframe complexity contributed most to cost escalation in the F-15A and F-22A comparison and the B-1B and B-2A comparison; not surprisingly, the F-22A and the B-2A are the two aircraft in the comparison table containing the most advanced materials.

Total Escalation

Table 5.3 summarizes economy-driven factors and customer-driven factors. We also note the contribution of "learning" over the course of

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[2] This de-escalation is due to a decrease in the maximum speed of the aircraft. Note, however, that the annual increase resulting from airframe complexity, 6.1 percent, more than offsets this reduction.

Table 5.3
Percentage Contributions to Annual Escalation Rate

Comparison	Economy-Driven Factors	Customer-Driven Factors	Cost Improvement Correction	Predicted	Actual
F-15A (1975) to F-22A (2005)	3.5	6.4	0.1	10.0	9.9
F/A-18A/B (1983) to F/A-18E/F (2003)	3.1	3.1	0.0	6.2	4.7
B-1B (1984) to B-2A (1993)	3.1	3.5	0.0	6.5	10.7
C-130H (1980) to C-17 (2005)	3.2	7.1	−0.2	10.2	12.8
E-3A (1975) to E-8C (2005)	3.4	2.3	−0.3	5.4	6.0
E-2C (1975) to E-2C (2004)	3.4	1.9	0.0	5.3	6.4
T-34C (1978) to T-6A (2001)	3.3	3.1	0.1	6.5	6.7
T-34C (1978) to T-45TS (2000)	3.3	11.9	0.0	15.2	15.9

production, shown in the Cost Improvement Correction column. This correction adjusts for the fact that, in some cases, we are comparing the aircraft programs at different points in the production run. For example, it would be misleading to compare the first or second airframe of an aircraft type to the 300th. This correction term puts the comparison on a uniform production experience level.

In comparing the aggregate of these estimates with historical escalation, we see that, except for the bomber comparison, predicted escalation tracks actual escalation closely. Four of the eight comparisons come within 1 percent of actual escalation; only for cargo and bomber aircraft did the difference between actual and predicted escalation exceed 2 percent. The small difference between the actual total cost escalation and that predicted by our model of disaggregating the contributions to economy-driven and customer-driven factors lends support to the validity of our disaggregation method and subsequent attribution of cost escalation to each set of factors.

The range of economy-driven factors is narrow, from 3.1 to 3.5 percent. The range of customer driven factors is wide, from 1.9 to 11.9 percent. This implies that the wide variability in cost escalation between pairs is almost entirely due to differing estimations of customer-driven factors. Pairwise comparisons with smaller actual escalation have a

larger share of that escalation explained by economy-driven factors; the proportion of escalation explained by economy-driven factors ranges from one-fifth (or 3.3 percent or a total of 15.9 percent) for the T-34C/T45TS comparison to four-sevenths (or 3.4 percent of a total of 6.0 percent) for the E-3A/E-8C comparison.

These trends all imply that the main source of cost escalation for aircraft is customer-driven factors or, ultimately, the increased performance and capability that has proceeded from decade to decade. This increased capability has come, in some cases, at a considerably increased cost. By contrast, economy-driven factors have remained fairly consistent across the aircraft types. In the next chapter, we explore aircraft manufacturers' perspectives on these and related issues.

CHAPTER SIX

Industry Views on Military Fixed-Wing Aircraft Cost Escalation

In addition to quantifying the variables that contribute to aircraft cost growth, we also visited and held lengthy discussions with the major prime contractors for fixed-wing military aircraft production. In this chapter, we examine what representatives of these firms said are the most significant reasons for aircraft cost growth. We also review other research concerning what the industry is doing to reduce or avoid further cost increase.

Military Fixed-Wing Aircraft Industry

The military fixed-wing aircraft industry has undergone considerable consolidation since World War II. In the 1940s, there were 16 prime contractors in military aircraft manufacturing, and even in 1990 eight of these remained (Birkler et al., 2003). Today, there are three prime aircraft manufacturing contractors with active final assembly and checkout production capabilities: Boeing, Northrop Grumman, and Lockheed Martin.

Boeing produces the F/A-18E/F for the U.S. Navy, the C-17 for the U.S. Air Force, and the F-15 for foreign military sales. Lockheed Martin produces the F-22A and C-130J for the U.S. Air Force and the three different variants of F-35, conventional take off and landing (CTOL), carrier version (CV), and short take off and vertical landing (STOVL) for the USAF, USN, and U.S. Marine Corps as well as for

the United Kingdom Royal Navy and the Royal Air Force. Northrop Grumman, in addition to being responsible for the final assembly of the E-2C aircraft for the USN, is a major partner with Boeing, producing the aft fuselage for the F/A-18E/F, and with Lockheed Martin, producing the center fuselage for the F-35.

Each of these prime contractors responded to a RAND questionnaire, reproduced in Appendix B, and shared their opinions during interviews on why the cost of fixed-wing aircraft has increased and what can be done about it. We have grouped these views into two categories: increased military utility and government requirements.

Increased Military Utility

The technological revolution in design tools, electronics, and propulsion technology has given aircraft designers the opportunity to create weapon systems of increasingly greater lethality and capabilities. This is especially true for combat aircraft such as the F-22A, the F/A-18E/F, and the F-35, whose complexity is substantially higher than that of their predecessors. For example, the F-16, the initial lightweight fighter of the 1970s, had 15 subsystems and thousands of interfaces but less than 40 percent of its functions managed by software. Today, the F-35 has 130 subsystems, hundreds of thousands of interfaces, and more than 90 percent of its functions managed by software. Furthermore, newer fighter aircraft include sophisticated electronic warfare capabilities, perform with higher thrust engines, and can evade the enemy radar far better than can legacy fighters such as the F-14, F-15, and F-16.

Stealth

Most industry observers note that stealth features have been major contributors to the complexity of combat aircraft. The new class of combat aircraft is much stealthier and evades enemy radar better than their predecessors. In addition to the tactical benefits that stealth offers, it also makes the system much more survivable. New computer-

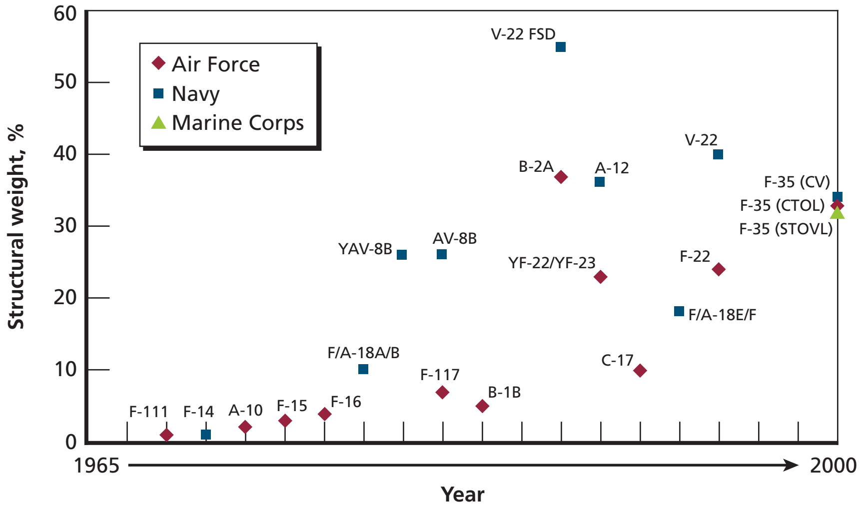
aided design (CAD) tools allow for three-dimensional design capability that has enabled designers to move away from nonaerodynamic stealth airframe design such as the F-117 to the highly aerodynamic and stealthy airframe of the F-22A and the F-35. CAD information can be directly fed to computer-aided manufacturing (CAM) hardware, such as five-axis, high-speed milling machines and automated composite fabrication tools. These tools can produce parts with extreme dimensional precision and tolerances, which lead to minimal or no appreciable gaps and mismatches, thus eliminating the need for any solid shims. Gaps and mismatches in the surface increase radar visibility, so eliminating them is a goal of any stealthy design. Improvement in radar absorbing materials (RAM) and their application in manufacturing has substantially benefited aircraft stealth. Adding these features requires additional nonrecurring design labor costs as well as recurring labor and materials costs, which all contribute to additional overall costs.

Weight Reduction

Weight has been the enemy of aircraft from the dawn of aviation. Designers constantly seek to reduce weight to increase performance. Yet modern aircraft require fly-by-wire capabilities and sophisticated electronics to enable them to communicate in hostile environments, jam enemy radars, and avoid surface-to-air missiles. These electronics add weight and require space on the platform. Increased maneuverability and speed also require complex, often heavy, propulsion systems.

The aircraft industry continuously introduces new lightweight materials and innovative structural designs to military airframes. Chief among these are composites, many of which are embedded in a resin matrix. This combination of materials is surprisingly lightweight in comparison to metals used to make the same parts, but their weight advantages come at a cost. Younossi, Kennedy, and Graser (2001) found that parts made from composite materials are generally more costly to design and manufacture in comparison to metal parts. Figure 6.1 shows that the use of composite materials in aircraft has increased over time.

Figure 6.1
Trend in Composite Material Use in Aircraft, 1967 to 2000



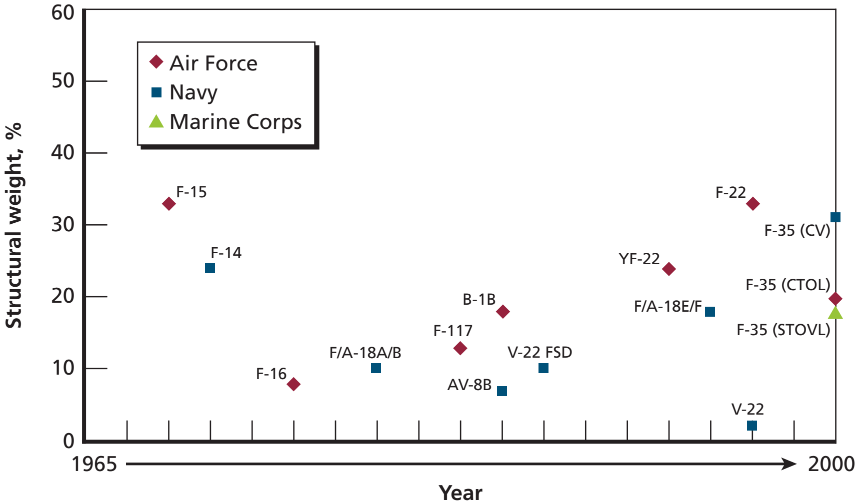
NOTE: FSD = full-scale deployment.
RAND *MG696-6.1*

Titanium is a lightweight, high-strength material that can withstand high temperatures. As Figure 6.2 shows, manufacturers used titanium in significant amounts in the late 1960s to produce the Navy's F-14 and the Air Force's F-15 aircraft and it is being used increasingly once again. The requirement for speed and high-temperature engines increased the need for it in the airframe structure, especially in the aft fuselage (Younossi, Kennedy, and Graser, 2001).

The F-16 and F/A-18A/B aircraft, however, emphasized affordability, so performance requirements were modified to permit the use of aluminum rather than titanium. More recently, the F/A-18E/F and, especially, the F-22A aircraft have emphasized performance, leading to more use of titanium.

In recent years, the commercial demand for titanium has increased substantially. This new demand is often called the "golf club" effect in reference to the use of the metal in golf clubs. Other manufacturers, including those making bicycle frames and tennis rackets, have also increased their use of titanium. Furthermore, the commercial

Figure 6.2
Trend in Titanium Use, 1967 to 2000



RAND *MG696-6.2*

aircraft industry has increased the use of titanium (Tran-Le and Thompson, 2005). Demand in China has increased also; titanium is used as an additive in steel production (Tran-Le and Thompson, 2005). This commercial demand has increased the need for raw material and has placed a tremendous burden on its suppliers. Every aircraft manufacturer we interviewed during this study raised concerns about the effect of commercial demand for the metal on aircraft manufacturing costs and schedules.

Lean Manufacturing

The principles of lean manufacturing were first introduced by Toyota, a Japanese automotive manufacturer, to improve the quality and affordability of their vehicles. These principles are a collection of activities focused on improving the entire enterprise, including

- product development, by incorporating ease of manufacturing and quality control during the design phase using integrated product teams (IPTs)

- continuous improvement during production, as recommended by production workers, through "Kaizen" events
- kitting of the material and tools required during assembly in especially designed "Kanbans" for ease of access
- design of the assembly for a streamlined product flow
- procurement of material from suppliers with whom the prime contractor has formed a strategic alliance, eliminating the need for rigorous quality checks and a large inventory of parts and materials through just-in-time delivery of materials and parts.

As with the automotive industry, the aerospace industry has implemented some or all of these initiatives in processing parts and subassemblies. Nearly all aircraft prime contractors and their major vendors have embraced at least the principles of lean manufacturing, realizing some cost savings. Although there is much anecdotal evidence and many pilot project results, there is no evidence that these principles were applied to the entire aircraft manufacturing enterprise (Cook and Graser, 2001). Although lean manufacturing approaches show promise for future savings, we could find no evidence in our historical examination that they measurably reduced prices.

Government Requirements

Aircraft manufacturers highlighted four areas of government policy as potential sources of aircraft cost growth. These were the Berry Amendment and "Buy American" legislation, Occupational Safety and Health Administration (OSHA) requirements and environmental regulations, antitamper requirements, and International Trade in Arms Regulations (ITAR). We discuss each of these below.

Berry Amendment and "Buy American" Legislation

Two laws restrict how aircraft manufacturers may purchase materials: the Berry Amendment (10 U.S.C. 2533a) and the Buy American Act (41 U.S.C. 10a–10d). Within the aerospace industry, the Berry Amendment applied mainly to specialty metals, requiring that these materials

be smelted in the United States. Recently, the specialty metals provisions was removed from this amendment and placed within 10 U.S.C. 2533b. The Buy American Act, originally passed in 1933 and amended a number of times since then, also restricts the purchase of material by aerospace contractors, particularly the purchase of material from overseas vendors. These two laws require that manufacturers of military aircraft forgo potentially less-expensive foreign sources of products that meet technical specifications in favor of U.S.-made materials. For certain critical industries, including aerospace, this requirement may flow down several levels to the subcontractor/supplier level. The laws have been in effect for decades, but several industry groups are currently seeking relief from some of them. The exemptions they are seeking include

- an exemption for commercial items
- an exemption that would allow manufacturers of dual-use items to commingle foreign and domestic specialty metals in production, provided they acquired the appropriate quantity of domestically smelted specialty metals
- a de minimis exemption allowing for delivery of an item containing noncompliant specialty metals if they constitute less than 2 percent of the total amount of specialty metals in an item.

OSHA and Environmental Regulations

Industry representatives also cited OSHA and environmental regulations as potential sources of cost growth. OSHA regulations ensure the health and safety of workers in the aerospace industry and include measures to help prevent employees from falling off large aircraft as well as requirements for respiratory gear and proper ventilation around such volatile chemicals as paints. These regulations could increase costs if new, exotic materials involve the greater use of volatile chemicals and, hence, investment in more protection for workers. Information about the direct effect of these regulations on aerospace manufacturing is sparse. Environmental regulations that control the emission of volatile chemicals into the atmosphere also mandate the need for an envi-

ronmental control facility for hazardous materials. The need for such a facility increases both direct and indirect costs of the products.

Antitamper Requirements

Antitamper requirements are relatively new policies to protect "critical" U.S. technologies by preventing their unauthorized access and duplication. Such measures may include encrypting software, coating of chips, or attaching explosives to sensitive compartments. Anti-tamper requirements are designed to prevent an enemy from studying and duplicating the systems on a downed aircraft and subsequently reverse-engineering them. Currently, antitamper measures are voluntarily implemented according to guidelines included in the *Defense Acquisition Guidebook.* The lack of a standardized definition for "critical technology," however, has made implementation of these requirements difficult. Antitamper requirements can increase costs by requiring additional design and manufacturing work and making maintenance and replacement more difficult.

International Trade in Arms Regulations

ITARs implement the Arms Control Export Act's (ACEA) requirements. They control the transfer of technologies, both military and commercial, to other nations. The actual regulations may be found under 22 CFR Parts 120–130. Globalization has made their application increasingly difficult in recent years, as manufacturers with globalized supply chains find it difficult to include their offshore plants and engineers in production and design decisions. This may increase expenses by complicating the design process or requiring greater controls on information. Many aerospace industry representatives whom we interviewed argue that these regulations are unnecessarily restrictive, because many restricted components are already manufactured by other countries. This regulation also affects what military products can be marketed and sold through foreign military sales.

Summary

Industry representatives we interviewed indicated three areas that have contributed to cost escalation for fixed-wing aircraft: (1) a diminishing industrial base (both at the prime and supplier levels), (2) increased military capability, and (3) broader government regulations. The second point is in agreement with our observations from the previous chapter—that customer-driven factors heavily influence the magnitude of the cost escalation. The other two areas, although important but difficult to quantify, are also viewed as contributing to price changes. However, the analysis presented in the chapters above suggests that these areas are less important to cost escalation.

CHAPTER SEVEN

Options for the Air Force and the Navy to Reduce Fixed-Wing Aircraft Costs

We did not conduct an exhaustive search of ways that the two Services might reduce the costs of their fixed-wing aircraft, but our interviews with aircraft manufacturers and other knowledgeable sources elicited seven preliminary suggestions:

1. Make fixed-wing aircraft procurement more stable and predictable
2. stabilize project management and design
3. rethink competition within the industrial base
4. encourage international competition and participation
5. improve the process of formulating requirements and capabilities process
6. focus attention on upgrades and commercial derivatives
7. increase the use of evolutionary acquisition principles.

Some of these ideas are highly speculative and, given the current fiscal and legislative environment, have dubious prospects for implementation. Nonetheless, for completeness of discussion, we address each below, pointing out both positive and negative aspects. We also discuss lessons learned and documented in previous RAND research on aircraft development programs. Note that some of these approaches may have to be addressed early in the acquisition phase to have a meaningful effect on the procurement cost.

Make Fixed-Wing Aircraft Procurement More Stable and Predictable

Manufacturers of military aircraft face two problems with respect to stability. First, initially planned quantities often differ greatly from the actual quantities produced. For example, the F-22A program initially anticipated that 659 units would be produced in the initial Selected Acquisition Report (SAR) dated 1991. By the 2005 SAR, the total number of aircraft had fallen to 186—a reduction of nearly two-thirds. The C-17 program planned 211 units in the initial SAR dated 1985. By 1990, the quantity had dropped to 121, dropped further to 41 by 1993, but rose to 181 by 2002.

Second, annual production quantities often vary significantly from year to year. For example, the F/A-18E/F fiscal year buys, excluding those for the first two years, varied from 30 to 48 units. The C-17 acquisition for the Air Force varied from 6 to 15 units each fiscal year (again excluding the initial procurement years). The F-22A procurement profile has ranged from 10 to 24 since the initial development production. In most of these cases, the production line was designed and equipped to accommodate a higher production rate than has ever been realized.

Such variability in procurement can add to the unit cost in two ways. First, by overestimating the actual quantity that will be produced, manufacturers scale facilities to a rate of production that will not be met. Hence when production quantities are lower than planned, manufacturing is not operating at the most economic point; for example, facilities are less than fully productive and inefficiencies are introduced through potential gaps or idle time. Second, the year-to-year variability in acquisition makes it difficult for the firms to manage their staffs and suppliers. With work levels varying by 50 percent or more, manufacturers sometimes must choose between releasing staff or placing them on overhead until the procurement rate increases again. By developing a realistic and steady production plan, the Services would permit manufacturers to size their production to a more economic scale and possibly take advantage of the corresponding higher productivity.

Multiyear buys or "advance appropriation" could introduce a greater semblance of stability to aircraft manufacture (Blickstein and Smith, 2002). The Air Force and Navy could also improve stability by resisting changes to its fixed-wing aircraft procurement plan with each budget cycle. There are other advantages to multiyear procurements—such as the option to purchase larger quantities of material and equipment (through Economic Order Quantities) to leverage efficiencies in the supply base. The Services have successfully used multiyear procurement to purchase F/A-18E/F, C-130J, AV-8B, KC-10, C-17, F-15, E-2C, and F-16 aircraft. The proposed savings reported range from 5.5 to about 11.9 percent for fighter and attack aircraft. The range of savings was even wider (5.5 to 17.9 percent) when we include other fixed-wing aircraft going back to 1982 (Younossi et al., 2007).

This procurement strategy would permit the Air Force, Navy, and aircraft manufacturers to establish contractual agreements for future aircraft over several years. Under multiyear procurement, Congress authorizes all procurement quantities and funding necessary in the first year but appropriates funds annually. Because multiyear procurements establish penalties against the Service for not procuring the specified number of aircraft, and because Congress rarely backs away from such an agreement once it is implemented, such agreements give manufacturers greater confidence in making investments and allow them to increase their purchasing leverage with suppliers. Multiyear procurement is advantageous to the aircraft industry because the method provides some advance notification of future procurement by the Air Force and the Navy, and thereby permits long-term planning and investment by manufacturers—such as optimized production schedules, more cost-effective ways of procuring materials and parts, and avoiding the need to prepare and negotiate proposals for the future lots (Younossi et al., 2007).

There are some downsides to the multiyear procurement approach, however. The savings resulting from multiyear procurement are very difficult to validate (Younossi et al., 2007). Most of the savings values are based on estimates and not actual costs. This difficulty is part of the reason the range of savings resulting from multiyear procurement is so large. A second downside of multiyear procurement is that the

approach limits future flexibility by the Congress or the Services. For example, if there were an emerging financial need during the contract that required a cut to the procured quantities, the government would have to pay substantial penalties to realize the reduction. A further downside is that multiyear procurement is effective only where there is design stability. Thus, the approach is really applicable only to programs when the production configuration is fixed.

Stabilize Project Management and Design

One possible way the Air Force and the Navy could potentially limit cost escalation is through improved management stability. For example, the Air Force and the Navy could curtail their current practice of rotating officers through jobs every three to four years. Because a fixed-wing aircraft may take up to two years to build and a program may stretch over decades, a single program could have several program managers, each with differing management methods and philosophies.

Management initiatives might also help reduce the number of changes during production. Although changes may result from new military threats or experience with earlier units, they are disruptive and expensive to the program. For example, we have seen that the total cost growth on military aircraft averages about 35 percent over the entire procurement (Arena et al., 2006b). Although not all of this growth is due to changes, some of it certainly is. During the early years of the Reagan administration, the Secretary of the Navy insisted on personally approving every change to a ship or aircraft contract. This, in effect, transferred such decisions away from acquisition officials and to his office. Such drastic measures can control changes.

Rethink Competition Within the Industrial Base

A recurring issue since the end of the Cold War has been the consolidation of the defense industrial base to reflect the defense budget

reductions during the 1990s. Considerable consolidation has already occurred within the fixed-wing aircraft base, with the loss of Martin Marietta, LTV, and McDonnell Douglas from the manufacturer base. Even Northrop Grumman, while remaining in the industrial base, builds portions of aircraft for Boeing and Lockheed rather than complete aircraft under its own name (except for the E-2). As a result, the United States now has only two fixed-wing fighter/attack aircraft manufacturers with a full systems integration capability. Prime aircraft manufacturing firms have noted a similar consolidation in their supplier base.

Given this dramatic consolidation, maintaining a competitive environment at the prime level remains challenging. Indeed, new design programs are few and far between. Thus, the loser of a competition faces bleak financial prospects. The use of competition at the prime level as a means of cost control will be limited. Given these realities, the Air Force and the Navy might encourage competition at the subsystem level (e.g., electronics and major subsystems). Yet, it is also unclear whether this subtier of the industrial base is robust enough for such a strategy, as some of these vendors are already sole sources for unique materials and specialized critical components (Office of the Under Secretary of Defense, 2007a).

There is an additional issue—that of the stability and sufficiency of the design base. With only the three manufacturers mentioned above, there is also a concern over maintaining a reasonable technical capability for aircraft design, especially as demands for new designs become less frequent. With the F-35, F-22A, and F/A-18E/F as the only high-technology aircraft currently in production for the U.S. military, and no new designs for manned aircraft on the horizon, the United States must remain concerned about who will design its next-generation aircraft.[1] If DoD decides to maintain such a small base, it will come at a cost.

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1 A few F-16s and F-15s are being produced for foreign military sales.

Encourage International Competition and Participation

For security reasons, Air Force and Navy aircraft production is limited to the United States. This makes sense from a defense perspective, but it limits the competition and innovation that might be realized from procuring aircraft in a global market. Allowing the Air Force and the Navy to buy from foreign companies might help increase competition and reduce costs. Some of our North Atlantic Treaty Organization (NATO) allies currently build both military and commercial aircraft, and companies such as BAE Systems and EADS have established U.S. companies or counterparts to bid on U.S. aircraft production, such as the new tanker aircraft. Competition or participation by foreign suppliers might have a positive effect on the U.S. fixed-wing aircraft industry. The globalization of the defense industry is, in general, an evolving process. For example, BAE and Rolls Royce, both UK companies, are participating in the development of the Joint Strike Fighter (JSF or F-35). Foreign companies are also increasingly buying U.S. companies. The purchase of United Defense by BAE Systems is one example. Still, involving foreign firms in the manufacture of U.S. fixed-wing aircraft could raise issues of access to and control of highly sensitive technology. Also, as discussed above, the Berry Amendment (10 U.S.C. 2533a), the Buy American Act (41 U.S.C. 10a–10d), and ITAR may limit initiatives and require waivers for participation of foreign firms.

Improve the Process of Formulating Requirements and Capabilities

The combined aviation capabilities of the U.S. Air Force and the U.S. Navy have no peer throughout the militaries of the world. Yet, the United States continues to build aircraft that push the edge of technology and capability. This technical advancement has its price in both schedule and cost. As a result, the concept of controlling the processes for new technologies has gained some popularity. For example, the Navy has instituted a board structure to review and approve initial

design and subsequent changes in requirements for new and in-service aircraft (and ships). At issue is whether each change is worth the cost, technical risk, and schedule change. These boards also consider the effects of changes on the contract with the builder. This consideration was called Cost as an Independent Variable (CAIV) in the mid-1990s when DoD attempted to view each incremental change in capability in terms of its cost.

It is too early to tell whether these boards are having the desired effect. The United States has technical supremacy in the aviation world today, and this technical edge would allow the Services to reduce the number of aircraft to meet mission needs and to reduce the risk to pilots and crews. Decisions on the numbers and capabilities of aircraft must include both military and business issues that require a high level of consideration within the two Services. In the case of the JSF/F-35, there has been some pressure to reduce the buys of aircraft and move the program further to the "right" in schedule terms, that is, to delay some production because of cost growth and increased technical risk.

Focus Attention on Upgrades and Commercial Derivatives

Another way to reduce the costs and technical risks of replacement aircraft would be to focus on modifications or changes to existing aircraft—on an upgrade[2] rather than buying new. The Services have pursued this strategy for some time, as with the B-52 in the Air Force, the E-2D in the Navy, and the CH-46 in the Marine Corps. However, the age of existing aircraft sometimes makes an upgrade option less feasible.

The Services have sometimes used commercially derived, modified airframes for military purposes. For example, the Air Force E-8 Joint STARS uses the B-707 airframe. Further, the Navy multimission maritime aircraft (MMA), a replacement for the P-3 Orion,

[2] By upgrade, we mean either a retrofit of an airframe already in the fleet (such as the upgrades to the B-52) or the introduction of a new series (such as the change from E-2C to E-2D).

will be using a B-737 airframe. Also, several commercial candidates exist for the U.S. Air Force tanker replacement program.

Both Services pursued a continuous cycle of technology improvements during the Cold War to match external threats. With no near-peer competitor today, they may be able to slow the pace of innovation, focusing instead on upgrades of existing aircraft to save cost and reduce technical risk. There is a severe downside to such a strategy, however. The design and engineering parts of the industrial base cannot simply lie fallow for a period of time and be expected to "sprout" anew when needed. Consolidation of remaining manufacturers and the elimination of any semblance of competition would also probably occur with this strategy.

Increase the Use of Evolutionary Acquisition Principles[3]

This concept aims to reduce the time between the identification of new operational needs and the delivery of an operational weapon system that meets those needs. Instead of a one-step process to building full capability, evolutionary acquisition aims to achieve desired capabilities over time, with phases of development divided into increments of operational capabilities (Lorell, Lowell, and Younossi, 2006). Once threshold capabilities are fielded, feedback from operational experience can be incorporated into the next increment or phase of development, thus reducing technical risk and increasing the probability of better cost estimates.

The benefits of this approach include a reduced likelihood of major research and development (R&D) delays and cost overruns. Drawbacks include the possibility that contractors may allocate easy development tasks to early iterations, leaving more difficult tasks for later stages, in hopes of getting the Service to commit to the project. Managers at both the contractor and Service levels are more important players in an evolutionary acquisition process. The flexibility in final requirements

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3 For a more complete discussion, see Lorell, Lowell, and Younossi (2006).

and capabilities could cause scope and cost creep. Finally, Congress is not generally happy with a program that is not fully defined at the time of authorization/appropriation and therefore may be less likely to support this approach when it involves large aircraft programs.

Lessons Learned from the F-22A and F/A-18E/F Development Programs

In addition to the ideas noted above by aircraft manufacturers whom we interviewed, we note here some ideas from lessons learned from previous RAND research on aircraft development programs. Specifically, earlier RAND research (Younossi et al., 2005) on the F-22A and F/A-18E/F programs may offer some more general lessons on controlling aircraft cost growth. Among its findings

- Each program used different methods to solicit contractor proposals and to divide the work among contractors in the design phase. The F/A-18 drew on preexisting relationships among its contractor base to minimize technology risks. It also implemented a strong CAIV strategy.
- Concurrent development of new technology created greater technical challenges for the F-22A, whereas incremental improvement reduced technical risk in the F/A-18E/F. Stealth requirements accounted for a big part of the difference between the two programs. The lower risk for the F/A-18E/F may have contributed to its stable cost and schedule.
- The programs allocated different portions of their budgets for management reserves. The F-22A allocated only 2 percent of its budget to management reserve whereas the F/A-18E/F maintained a 10 percent reserve. Thus, the F/A-18E/F was more likely to have the reserves to fix program problems. Given the differences in the risk for the two programs, it seems that the F-22A should have had the higher proportion for management reserves.

- General program lessons included
  - Early, realistic, cost and schedule estimates set programs on the right path for development.
  - A stable development team structure, proper team expertise, clear lines of responsibility and authority, and a lead contractor responsible for the overall program progress are critical to program success.
  - An experienced management team and contractors with prior business relationships help eliminate early management problems.
  - Concurrent development of new technology for the airframe, avionics, and propulsion adds significant risk.
  - Reducing the cost and risk of avionics should be a key focus of the concept development phase. Avionics is a key cost driver of modern weapon systems.
  - Preplanned, evolutionary modernization of high-risk avionics can reduce risk and help control costs and schedules.
  - Careful monitoring of such major cost drivers as airframe weight is important. Dramatic changes to the planned airframe weight over time are an early indicator of problems.
  - Earned value management (EVM) data should be used to monitor and manage program costs at the level of integrated product teams.

Summary

There are several ways to potentially reduce fixed-wing aircraft costs, but few are plausible or palatable given current realities. For example, neither Congress nor DoD are likely to permit competition to build U.S. military fixed-wing aircraft in the international market. Prior attempts to balance cost and requirements have met with limited success (e.g., the CAIV concept has been around several years). Focusing attention on upgrades of existing systems could result in systems that are less capable or might have higher ownership cost. Although the nation, the Air Force, and the Navy understandably desire technology

that is continuously ahead of current and potential competitors, this comes at a cost. We do not evaluate whether the cost is too high or low; we note only that it exists.

CHAPTER EIGHT

Conclusion

We have found that the cost of military aircraft has increased in recent decades by 7 to 12 percent. This is about twice the rate of common inflation measures during this same time. Given that long-term defense investment spending, although somewhat cyclical, will remain relatively constant, this means that the government can afford to buy fewer, increasingly expensive aircraft. In fact, in "peak" defense funding years, the government is now purchasing fewer aircraft than it did during trough years of a few decades ago.

To address the sources of cost escalation in military aircraft, we analyzed both economy-driven variables, or those over which the Services have little control, and customer-driven variables, or those that they can influence. Among economy-driven variables are labor, material, equipment, and manufacturer fees and profits. Although labor costs have grown slightly faster than inflation, these increases have been offset by gains in productivity. The costs of materials and equipment grew at rates slightly below that of inflation but have recently exceeded it. The limited data available on fees indicate that changes in these costs have not accounted for much cost growth, probably as a result of how DoD establishes fees on its contracts. Altogether, our research found that the contributions of economy-driven variables to aircraft cost escalation were slightly below the rate of consumer inflation.

By contrast, customer-driven variables, such as the technical characteristics of an aircraft, procurement rates, and complexity of the airframe, have contributed substantially to cost escalation. We found that customer-driven variables contributed more to cost escalation than did

economy-driven variables for four of eight comparison pairs of aircraft that we examined. The economy-driven escalation was fairly consistent over the timeframe studied and for all pairs—roughly 3.5 percent. The customer-driven contributions varied widely—anywhere from about 2 to 12 percent.

Interviews with aircraft manufacturing industry representatives confirmed the contribution of customer-driven variables to aircraft cost escalation. Specific features said to be driving costs include those for greater stealth of aircraft as well as demand for composite materials that can help reduce aircraft weight. Beyond these specific government requirements, broader government policies, such as those requiring U.S. materials, occupational and environmental regulations, and safeguards to protect U.S. critical technologies, are felt to contribute to cost escalation.

We examined several options to reduce cost escalation—none of them are a panacea. If the Services wished to benefit from more competition, they could encourage international competition and participation in the construction of military aircraft. Given likely opposition from Congress to such an initiative, and hence a very low likelihood for its implementation, the Services may wish to consider other means to reduce costs, such as stabilizing procurement rates and management, or incorporating lessons learned into development programs for some aircraft.

One more direct way to control cost escalation would be to curb requirements growth over successive generations of aircraft and focus on incremental improvements. Such an approach, however, could slow the pace of innovation and potentially risk losing the technical edge the United States has over potential threats.

The Services have been moving toward reduced procurement quantities as a way to stay within annual procurement budgets. These reductions have helped them continue to procure aircraft that remain far superior to that of any other military in the world. Maintaining such capabilities is not, of course, a bad thing. Technological superiority in the air means that the United States can continue to deter and defeat adversaries. But it does result in increased unit costs, as we have

attempted to illustrate. Knowing this can help the Services make the increasingly difficult choices between individual aircraft capabilities and total numbers of aircraft.

APPENDIX A

Aircraft Included in the Analysis

In Chapters Two and Four, data limitations required that we use varying subsets of aircraft systems for different parts of the analysis. These subsets are "chunks" (not random samples) that were selected on the basis of (1) data availability, (2) time-period suitability, and (3) consistency with the requirements of regression models.[1] In Table A.1, we present the entire universe of aircraft considered in the analysis and indicate which aircraft form the chunks used in analyses of (1) broad cost trends, (2) cost improvement slope, (3) cost improvement slope with procurement rate (PR) slope, (4) basic technical characteristics, (5) advanced materials, and (6) mission type. In Table A.1, an "X" indicates that an aircraft type is used in the analysis described in the column heading; those analyses can be found summarized in the table or in the tables listed in that column. Mission types are broad categorizations, as both tanker and transport missions are listed as cargo. For many current aircraft, the patrol mission has been integrated into the electronic mission, yet the distinction has been maintained for older aircraft.

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1 See Deming (1950), p. 14: "A judgment-sample is planned with expert judgment. A chunk is dictated by convenience."

Table A.1
Aircraft Systems and Types Used in the Analyses

		Cost Trends (Tables 2.1, 2.2), 67 Aircraft Types	CI (at Least 5 Lots) (Table 4.1), 52 Aircraft Types	CI and PR (at Least 5 Lots) (Tables 4.2, 4.3), 24 Aircraft Types	Technical Characteristics (Table 4.6), 93 Aircraft Types	Advanced Materials (Table 4.7), 49 Aircraft Types	Mission Type
1	A-10A	X	X	X	X	X	Attack
2	A-1G				X		Attack
3	A-1J				X		Attack
4	A-3A				X	X	Attack
5	A-4E				X		Attack
6	A-4M	X			X	X	Attack
7	A-5A				X	X	Attack
8	A-6A		X		X	X	Attack
9	A-6E	X	X	X	X	X	Attack
10	A-7A				X	X	Attack
11	A-7B				X		Attack
12	A-7D/K	X			X	X	Attack
13	A-7E	X	X	X	X	X	Attack
14	AC-130H/U	X			X	X	Attack
15	AF-2		X	X	X		Attack
16	AV-8A	X	X	X	X	X	Attack
17	AV-8B	X	X	X	X	X	Attack
18	B-1A	X			X		Bomber
19	B-1B	X	X		X	X	Bomber
20	B-2A	X			X	X	Bomber
21	B-52				X		Bomber
22	B-58				X		Bomber
23	C-12F	X			X		Cargo
24	C-130E				X	X	Cargo
25	C-130F				X	X	Cargo
26	C-130G				X	X	Cargo
27	C-130H	X	X	X	X	X	Cargo
28	C-130J	X	X		X	X	Cargo
29	C-137E	X					Cargo
30	C-141A				X		Cargo

Table A.1—Continued

		Cost Trends (Tables 2.1, 2.2), 67 Aircraft Types	CI (at Least 5 Lots) (Table 4.1), 52 Aircraft Types	CI and PR (at Least 5 Lots) (Tables 4.2, 4.3), 24 Aircraft Types	Technical Characteristics (Table 4.6), 93 Aircraft Types	Advanced Materials (Table 4.7), 49 Aircraft Types	Mission Type
31	C-17	X	X		X	X	Cargo
32	C-2AR	X	X	X	X		Cargo
33	C-29A	X					Cargo
34	C-32B	X					Cargo
35	C-37	X	X	X			Cargo
36	C-40A	X	X				Cargo
37	C-5A	X			X	X	Cargo
38	C-5B	X	X		X	X	Cargo
39	C-9	X	X	X			Cargo
40	CT-39E	X			X		Cargo
41	CT-39G	X			X		Cargo
42	E-2A		X		X		Electronic
43	E-2C	X	X		X		Electronic
44	E-3A	X	X		X		Electronic
45	E-4A/B	X			X		Electronic
46	E-6A	X			X	X	Electronic
47	E-8B	X					Electronic
48	E-8C	X	X		X		Electronic
49	EA-6A				X		Electronic
50	EA-6B	X	X	X	X	X	Electronic
51	EC-121K		X		X		Electronic
52	EC-130	X	X	X	X	X	Electronic
53	F/A-18A/B		X		X	X	Fighter
54	F/A-18C/D		X		X	X	Fighter
55	F/A-18E/F		X		X	X	Fighter
56	F-104				X		Fighter
57	F-111A				X	X	Fighter
58	F-111F	X			X		Fighter
59	F-117				X		Fighter
60	F-14A	X	X	X	X	X	Fighter

Table A.1—Continued

		Cost Trends (Tables 2.1, 2.2), 67 Aircraft Types	CI (at Least 5 Lots) (Table 4.1), 52 Aircraft Types	CI and PR (at Least 5 Lots) (Tables 4.2, 4.3), 24 Aircraft Types	Technical Characteristics (Table 4.6), 93 Aircraft Types	Advanced Materials (Table 4.7), 49 Aircraft Types	Mission Type
61	F-14A+	X			X		Fighter
62	F-14D	X			X	X	Fighter
63	F-15A/B	X	X		X	X	Fighter
64	F-15C/D	X	X		X		Fighter
65	F-15E	X	X	X	X	X	Fighter
66	F-15E (ADV)	X	X				Fighter
67	F-16A/B	X	X	X	X		Fighter
68	F-16C/D	X	X	X	X		Fighter
69	F-16N				X		Fighter
70	F-22A	X	X		X	X	Fighter
71	F-4A		X		X	X	Fighter
72	F-4B		X	X	X	X	Fighter
73	F-4E	X			X	X	Fighter
74	F-4J		X	X	X	X	Fighter
75	F-5E	X			X	X	Fighter
76	HC-130	X					Cargo
77	LC-130	X					Cargo
78	KC-10A	X	X				Cargo
79	KC-130F				X	X	Cargo
80	KC-130J	X	X	X	X	X	Cargo
81	KC-130R	X			X	X	Cargo
82	KC-130T	X			X	X	Cargo
83	KC-135				X		Cargo
84	MC-130H	X	X				Cargo
85	OV-1	X					Patrol
86	P-2D				X		Patrol
87	P-2F				X		Patrol
88	P-2H		X	X	X		Patrol
89	P-3A				X	X	Patrol
90	P-3B				X	X	Patrol
91	P-3C	X	X		X	X	Patrol

Table A.1—Continued

		Cost Trends (Tables 2.1, 2.2), 67 Aircraft Types	CI (at Least 5 Lots) (Table 4.1), 52 Aircraft Types	CI and PR (at Least 5 Lots) (Tables 4.2, 4.3), 24 Aircraft Types	Technical Characteristics (Table 4.6), 93 Aircraft Types	Advanced Materials (Table 4.7), 49 Aircraft Types	Mission Type
92	P-5B				X		Patrol
93	PC-6						Patrol
94	RC-12						Electronic
95	RA-5C				X		Patrol
96	S-3A				X	X	Patrol
97	T-2C	X			X		Trainer
98	T-33B		X	X	X		Trainer
99	T-34C	X	X	X	X		Trainer
100	T-38A						Trainer
101	T-39A	X			X		Trainer
102	T-44A	X			X		Trainer
103	T-45A	X	X	X	X	X	Trainer
104	T-46A						Trainer
105	T-6A (USAF)		X		X		Trainer
106	T-6A (USN)		X		X		Trainer
107	TA-4F				X		Trainer
108	TA-4J		X	X	X		Trainer
109	TAV-8A	X					Trainer
110	U-2	X	X		X	X	Electronic
111	UC-12B	X	X				Cargo
112	UC-35	X	X				Cargo
113	UV-18	X					Cargo
114	V-22 (USN)	X	X				Cargo
115	VT-39E				X		Cargo
116	WC-130	X					Cargo

APPENDIX B

Survey of Industry

RAND was tasked by N81 and SAF/AQ to learn the reason for the phenomenal cost increases of military fixed-wing aircraft over the past three decades. To that end, we analyzed the information available to the Navy and Air Force cost analyses organizations.

During our discussions with the aircraft industry leaders, we hoped to examine how unit procurement costs have changed over time (i.e., why do aircraft today cost more than they did 30 years ago?). We also wished to share our preliminary observations with the aircraft industry leaders so that their insights and data could further inform our analysis.

Below is a list of seed questions used to jumpstart these meetings. The list was a starting point only. Other related topics were welcome.

1. In your view, what are the primary sources of military aircraft cost escalation for the past several decades?
2. How has the complexity of military aircraft evolved? What metrics do you think best capture the evolution in the complexity of fixed-wing aircraft (i.e., material mix, complexity of avionics, systems integration, low observability, and such)?
3. Are there any changes to contractual, regulatory, and statutory requirements that you believe may have added to the acquisition costs of military aircraft over the past six decades (i.e., contract military specification requirements, quality assurance requirements, OSHA requirements, government oversight or environmental requirements)? If so, how can we quantitatively or qualitatively capture or reflect their effects on aircraft costs?

4. Overhead costs have grown in the past few decades. Do you have any data that illustrate the increase in overhead costs? Can you identify the main contributors to the overhead cost growth (e.g., retirement, health care, and other benefits)?
5. Please tell us about the changes in the industrial base that may have affected military aircraft costs (e.g., diminishing sources of materials and equipment, lack of competition at the subvendor level, or flow down of government requirements).
6. Have any government reporting requirements changed in the past six decades (i.e., earned value, cost data reporting, or CDRL requirements)? Do you believe that any of these requirements have added to military aircraft costs?
7. What initiatives can the government encourage to reduce the cost of future military aircraft (e.g., multiyear acquisition, lean production, contractual incentives for cost reduction, and such)?

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